EPOC-alypse Mind Controlled Car

Senior Design I Project Documentation

GROUP 21

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1: Executive summary

The idea of having the power to control physical objects with your mind has been a fantasy of many people ever since first watching Star Wars. So for all of the people who have ever wanted to use the force, this project is right up your alley. The project that will be undertaken will be a small remote controlled car with an onboard computer that will interpret EEG (electroencephalography) readings from a headset worn by the user, and, depending on the type of brain activity detected, either move the car forward, backward, left, or right. The reason for incorporating EEG is to explore the emerging field of brain computer interface (BCI). Until recently the field of BCI has been primarily focused on that of neuroprosthetics applications that aim at restoring function to damaged parts of the body, but now, commercially available headsets make it possible for the field to broaden its view. Theses commercially available headsets are intended for use with videogames and integrating with the user's ordinary computer allowing for endless possibilities.

The main objective of the project is to design a functioning car that will respond to a user's brain activity and respond accordingly. Being used will be an Emotiv EPOC EEG headset to gather the necessary brain readings to drive the car. To run our custom architecture we will be using the Intel DH61AG mini-ITX motherboard with in Intel core i3 processor to communicate with a custom Arduino PCB that will translate a string sent out by a translation program on the mainboard and convert it into an 8 bit format that is able to be read by the custom PCB on the car. The car itself will house another custom PCB that will have a serial to parallel converter to drive the motor. The car also will have limiters on its actions, such as a speed limiter, so it does not wildly speed off when a signal is received and steering limiters, which decrease the turning angle to just 45 degrees so the user is able to control the car more fluidly and accurately.

This paper describes how each of the components listed above were researched and how they were implemented, including a budget and a timeline for finishing the EPOC-alypse mind controlled car for the final senior design presentation. In order to make the car respond as accurately as possible training on the Emotiv headset is essential. The ability to focus your mind and activate certain areas of the brain on command is the key to making this entire project work.

No experts or guidance from anyone who has used the headset before or who has in depth knowledge on the brain were referred to during the course of this project. This resulted in a well refined knowledge of how specific areas of the brain worked and what the thoughts that controlled the car actually meant.

There are also requirements from the hardware and software interfaces that will be dealt with, these are listed in the body of this paper. All these requirements led us to our budget, which since our group is unsponsored, was initially a fairly small number due to the financial situation of team members. This, however, changed dramatically due to the hardware that was required to run all of our systems properly. This is outlined more in the budget section of the paper.

2: **Introduction**

2.1: Motivation

Brain computer interface seems to be narrowly focused on the medical applications, but a much broader applicability of BCI exists than just medical uses. This project aims to expand into the realm of alternative uses for BCI by applying it to everyday activities. As more is understood about the brain and how it works, the more its power will want to be harnessed. Manipulating physical objects just by thinking is the ultimate goal for this area of interface. As a group of electrical and computer engineers the prospect of this is too enticing to pass up, therefore a mind controlled car was the perfect choice. The ability to apply this project to people who no longer and move their arms and legs was also a driving factor, just by simply replacing the remote for the car with the joystick for a wheelchair someone who is confined to a bed or otherwise immobile can become mobile.

2.2: Project Objective/Goals

The objective of this project, on paper, is quite simple: to build a remote controlled car that is controlled by your mind by using the Emotiv EPOC EEG headset. We came up with this project due to a unanimous interest by all members in the group.

Our goal is to control the car using thoughts via Emotiv EPOC.

- Control the car using a mini ITX board
- Get the commands from Emotiv EPOC and process them.
- Design an architecture to connect both the ITX and Emotiv, and that is extendable to incorporate multiple devices.

- Establish adequate connections and fine tune the signals for smooth controlling of the car.

The initial purpose of this project is to practically solve a way to manipulate physical objects with your mind. The main goal will be to navigate the car using the headset through a simple obstacle course. This course will consist of left and right turns on a circular track.

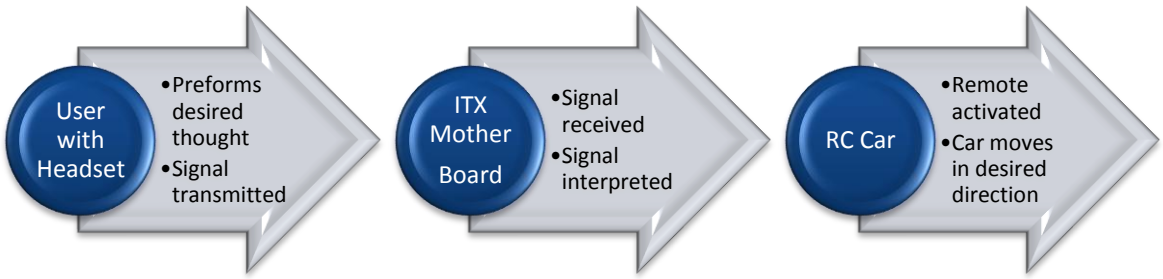

Figure 2.1 Basic flow diagram of how the EPOC-alypse car will work.

There are also many personal goals associated with this project as well. Many of which included getting hands on experience with the various topics and technologies, which would like to be pursued further in future careers. The more experience that is gained while working with a brain computer interface such as Emotiv's, the more we can explore the emerging technologies that incorporate the human brain.

2.3: Specifications

Below is a brief list of specifications that are a necessity for the project. These guidelines are the main aspects of the design that will have to be obtained for the project to work. Everything else can be changed.

Headset proficiency	Control four different actions Mastery of isolating thoughts
Motherboard	2.4 GHz processor 1 GB RAM 50 MB disk space USB 2.0 port
Car	Range of 40ft Full range of motion

(Table 2.1) Specifications table

2.4: Previous Works

Using the power of the human mind to control everyday objects had always been a fantasy for people. The possible applications and benefits of reading and interpreting brain-waves are endless. Examples of possible uses include medical devices for doctors and patients, new ways to control devices without a remote control, etc. Recently, however, several projects have arisen that have started to make this fictional desire into a reality. Projects such as the BrainDriver, the SWARM Extreme, RC Mind Control, and Brain-Controlled NXT Robot are beginning to use brain-waves as a means of allowing a user to control devices and applications. These projects are very similar to this project because they incorporate the use of an EEG headset and use data from it to control a device with brain waves or facial expressions.

2.4.1: BrainDriver: A Mind Controlled Car

At the Freie Universitat Berlin, Raul Rojas an AI professor have demonstrated how brain interface can drive an actual car. The project uses the Emotiv neuroheadset that feeds the commands received from the driver to the drive-by-wire system installed on the vehicle. The thoughts control the engine, breaks, and steering. While nifty the BrainDriver application is still a demonstration and not road worth because there is a two to three second delay in the response time. But the researchers say that future applications could be an autonomous cab ride, where a passenger could decide which route to take when more than one possibility exist.

2.4.2 The SWARM Extreme

The SWARM Extreme was a project carried out at Northeastern University in 2011 (Bothra). This project used the Emotiv EPOC headset to control an AR Drone without the use of a remote control. The processor used for this project was an ARM9 processor which was embedded in the AR Drone and interpreted signals sent from the laptop running the Emotiv software. The software design consisted of a client/server architecture that used the signals received from the headset and processed them into usable signals for the drone (Bothra). A buffer was used in the client in order to prevent over-whelming the Drone with too many commands. The project used a library written in Python to hack the Emotiv software. By using this software, it was possible to attain raw EEG data from the EPOC headset.

2.4.3: The RC Mind Control Project

The RC Mind Control project was carried out in The Center for Research in Arts, Technology, Education, and Learning (CRATEL) at Wichita State University. Initially, this group attempted using the NeuroSky headset, but found that its capabilities were not sufficient for this project. They found that the NeuroSky headset could only read brainwaves from one side of the brain. This made it very difficult to get usable and accurate data. After discovering this, they decided to use the Emotiv EPOC headset due to its more mature development and more accurate readings. A very important feature of the EPOC headset was that it provided them with enough data points to incorporate research done by Jonath R. Wolpaw and Dennis J. Mcfarland by using an equation that was determined by these two authors. The equation allowed them to calculate the direction in which the RC car was supposed to move by using the amplitudes of the signals sent by the EPOC headset. This group decided to use an Arduino board to

communicate with the remote control of the car. Instead of connecting the Arduino to the circuit on the car, they decided to connect the Arduino to the actual remote control. The Arduino then sent processed signals to the remote control which were then sent to the car.

The operation of this prototype required the user's level on concentration to be above a level of 0.599. The level of concentration as well as the position of the user's head were determined using the various suites included in the Emotiv SDK as well as the built-in accelerometers. Once the level of concentration was interpreted to be above .599, the Arduino processed the received signal and sent the proper signal to the remote control. The direction in which the car moved was determined by the position of the user's head. For example, to move the car forward, the user had to tilt his head up. After a signal was received, the software waited for the next signal from the headset to reach the Arduino board. When the user wished to stop the car, he simply relaxed his level of concentration and tilted his head back to a centered position.

2.4.4: The Brain-Controlled NXT Robot

The Brain-Controlled NXT Robot was a project carried out by a PhD student at Madeira Interactive Technologies Institute. Although this project does not control a car, it is a similar project to ours because it uses the EPOC headset to control a Lego Mindstorms NXT Robot. This project used an ARM7 microprocessor which was embedded in the robot. This project consisted of two prototypes. One of the prototypes used the NeuroSky headset and the other used the EPOC headset. This was done in order to show the different features and functionalities of the two distinct headsets. The NeuroSky headset used an algorithm provided by Neurosky in order to get attention and meditation levels of the user. The patterns that were found by the headset were then used to send commands to the robot. The Emotiv EPOC headset, on the other hand, used facial expressions as well as frustration, excitement and other emotions in order to produce data.

The software used on the ARM processor included a Java Virtual Machine called LeJOS. This was used as the OS for the project because it provided the "extensibility and adaptability of JAVA" (NXT ROBOT). This was important for this project because Java was the programming language used in this project with the use of Eclipse as the IDE. In order to connect the computer and the robot, a Bluetooth connection was used along with the pccomm and bluecove libraries found in the LeJOS API. This project used a very similar technique as the RC Mind Control project because they used a threshold value to determine when the signal sent by the headset was strong enough to be considered

intentional. In order to determine the threshold value, readings were taken for concentration levels while calm, normal and concentrated. These values were used to determine a level that would certainly determine when the user was concentrated. This experiment was conducted with five different users, thus making the results more general for all users. When the concentration level dropped below the threshold, the robot was instructed to stop moving. In order to monitor the attention levels of the user, the NeuroSky headset used the Mindset development tools along with a software program called LiveGraph, which plotted the concentration levels of the user with real-time data.

After researching many projects, these three examples were most relevant to the project that this group will be designing. Different headsets were analyzed as well as different devices such as cars, drones, boats, etc. This was very useful for this project because it helped minimize time wasted on ideas and procedures that would not have worked. By looking at the implementations of other projects, ideas were found that will allow this project to be more successful.

3: Project Definition and Scope

3.1 Definition and Scope

The EPOC-alypse controlled Car is a project that will combine the efforts of both computer software and hardware components. Both areas of study will work together in this project in order to control a remote control car by reading and interpreting EEG waves from the human mind as well as facial expressions. The final functionality of this project will be to be able to run the developed software and control the car without having to use any remote controls or having any other human interaction with the car. The scope of the project will be a final product that can function as stated above and that can be finished within one semester of research and one semester of work.

3.2 Span

The span of this project will consist of many fields of study including device communication, signal processing, hardware manipulation and many others. Device communication will be used in order to send the signals from one component to another. Without this knowledge, it will be impossible to accomplish the main task of the project. Signal processing will be used in the software aspect of the project. The signals received from the headset will be processed and categorized as being either cognitive or effective. Once this classification is done, the signals will be further processed into useful signals for the car to use. Hardware manipulation will be a very important aspect of this project. The car that we use in this project will have a custom PCB attached to it which will contain many sensors and components that will specifically used for the intentions of receiving signals from the motherboard and transmitting the correct voltages to the correct wires on the car. This PCB will control the motors as well as the servo motors and the piezoelectric ultrasonic proximity sensor on the car. There will also be a custom PCB connected to the motherboard that will be used in the signal processing aspect of the project. This PCB will be made to mimic an Arduino board and will convert strings into 8-bit streams of data that will then be used by the car to determine which command it should execute.

3.3 Assumptions

As with any project, there will be some assumptions made while making this project. First of all, it will be assumed that the environment in which the system is used will not cause any significant interference with the signals being sent by the headset. The signals being sent to the motherboard will need to be considered valid and if any signals are corrupted or lost, there is the possibility that the car will behave unpredictably. Also, it will be assumed that the user will have a complete mastery of the headset prior to using the project. Although it would be beneficial to assure that anyone can use the project, unfortunately the Emotiv EPOC headset requires much training before the signals sent by the user can be considered reliable. This is, of course, something that we cannot change and therefore we will be assuming that the user wearing the headset will be one of the group members which will have gone through all the necessary training in order to use the headset effectively.

3.4 Requirements

There will be a couple of specific requirements that will need to be fulfilled by the end of the project. The most basic requirement will be a functional car that will be able to respond to the signals sent by the EPOC headset. The other requirement for the project will be that it will be able to work as long as it is kept in range. The receiver on the car and the transmitter on the motherboard will have a maximum range that will ensure reliable signal transmission. The car will need to be able to function as long as it remains within this range, meaning that there will not be any bugs or unhandled exceptions in the software. There are no requirements for how fast the car will travel. This will be determined through testing.

3.5 Measuring Success

The overall success of this project will be measured by how accurate the car's actions are compared to the signals sent by the user. This will mean that both correct actions and response times will be taken into account. In order to achieve these results, it will be important to have hardware components that will meet all the requirements necessary to run the Emotiv software as well as transmit all the signals from the headset to the motherboard and from the motherboard to the car. It will also be important to develop software that will be able to interpret and process signals efficiently enough to produce real-time execution

4. Research

Brain-computer interface is a direct communication pathway between the brain and an external electronic device. The goals of BCI are often directed at assisting or augmenting human cognitive or sensory motor functions. Recently neural interface devices have become available on the market for gaming and other virtual uses. Neurosky, a company who offers one of these headsets gathers raw EEG data to use with applications on iOS and Android platforms. Their headset contains one sensor on the frontal lobe to collect multiple mental states. As the company puts it “the physics of brain waves is virtually identical to the physics of sound waves where a single microphone can pick up the complexity of the concert.” Another company who is in the same market is Emotiv, the headset this project utilizes. This headset contains 14 different sensors that are divided up into 7 pairs, which makes it better for reading the cognitive thoughts of a person.

So what are EEG (Electroencephalography) signals exactly? EEG is essentially the recording of electrical activity across the scalp, measuring the voltage fluctuations resulting from ionic current flows within the brain. These ionic current flows are maintained by neurons which obtain their charge from membrane transport proteins that act as simple pumps transporting ions across the cells membrane. So the way the headset picks up readings is that when one neuron releases a large amount of ions, these ions can push against other neurons, which push against others and so on. This is known as volume communication, and when that wave reaches the electrodes on the EEG detector they can exert a force on the metal inside each electrode. This difference in pushing or pulling on the metal between two electrodes is recorded as the EEG reading.

The Emotiv EPOC EEG Neuroheadset has 14 saline felt based electrode sensor receivers. Each sensor is ideally mapped and conveniently placed in the 14 different areas and lobes of the brain for optimal measurements. All of these 14 lobes and areas are divided into specific regional areas each has different functional aspects.

- The FRONTAL LOBE : Planning, Language, Expression and Speech contains the Motor cortex area involved in movements (movement, conscious thought , and controls voluntary movement of body parts),
- PARIETAL LOBE: Touch, Taste contains the Somatosensory cortex areas (receives and processes sensory signals from the body) ,
- OCCIPITAL LOBE visual area (contains the visual cortex) receives and processes signals from the retinas of the eyes,
- TEMPORAL LOBE :Language Reception.

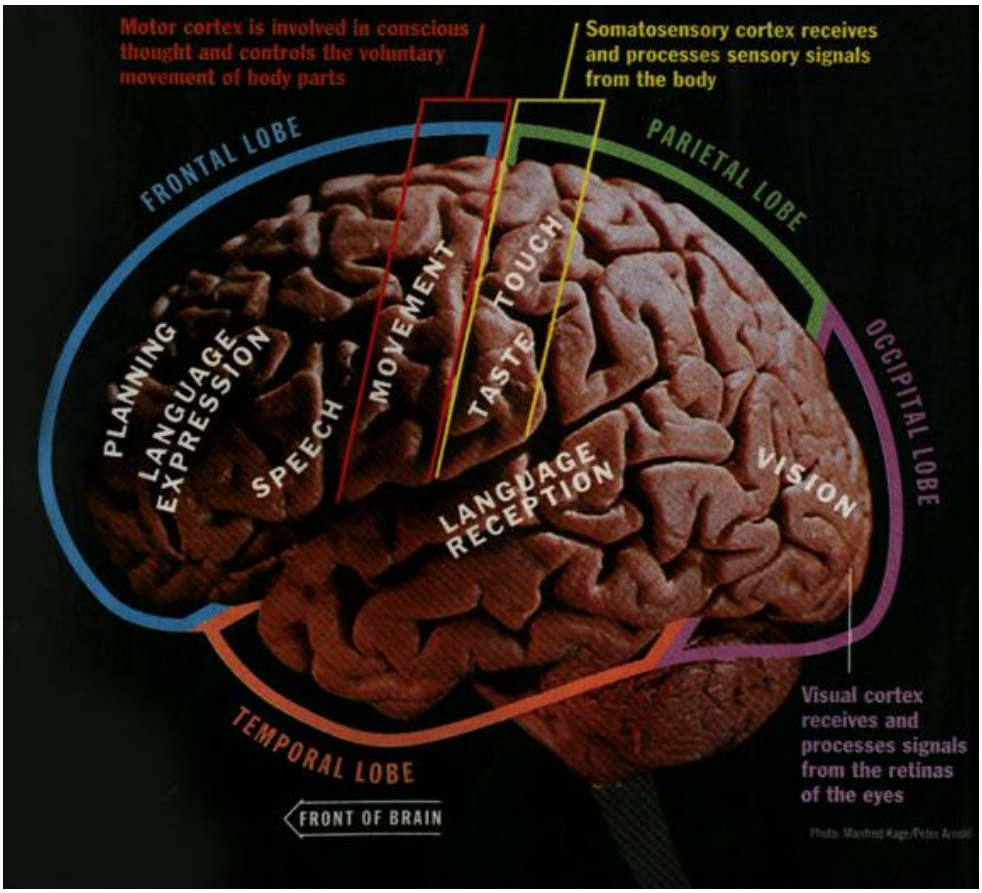

Figure 4.1 Lobe locations on the brain.

The 14 channels AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 shows real time brain wave activity divided into common brain wave frequencies Alpha, Beta, Theta and Delta. The sense 14 locations are given in the Hardware overview of the Headset section which has a diagram of each of the sensors to

be used and how they are each mapped to specific areas for different types of readings in the brain based on activity.

4.1 Brain Waves

These waves that are produced from the volume communication between neurons can be classified into; Delta, Theta, Alpha, Beta, and Gamma waves. There are also Mu waves but for or project these are irrelevant. The table below describes the frequency of each wave and what state of mind each occurs at.

Wave Type	Location	Frequency (Hz)	States of Mind
Delta	Frontal cortex	0 - 4 (high amplitude)	Asleep
Theta	Locations not related to task being preformed	4 - 8	Drowsiness, Idling, Arousal
Alpha	Posterior regions, either side of the brain	8 – 13	Relaxed, eyes are closed
Beta	Either sides of the brain but mostly in frontal region	13 – 30	Alert, working, anxious, busy
Gamma	Somatosensory cortex	30 – 100	Cross modal sensory processing (i.e. combining sight and smell)

(Table 4.1) Brain wave types and characteristics.

The project utilizes mostly Beta and Theta waves, thought delta waves seemed to present themselves more in the evening when the mind starts to start its night cycle.

While the type of brain waves that are exhibited are useful for initial training to try and obtain the proper mind set it is not what is being quantified for the EEG readings to control the car. This comes from the locations of the sensor pairs oriented around the skull. These areas are referred to as Brodmann areas.

4.2 Brodmann Areas

A Brodmann area is a region of the cerebral cortex defined based on its cytoarchitectonics, or structure and organization of cells. Many of these areas have been defined solely on neuronal organization and have since been correlated closely to a wide range of cortical functions. Below in figure 4.1is a rough diagram of where each area is located in the brain.

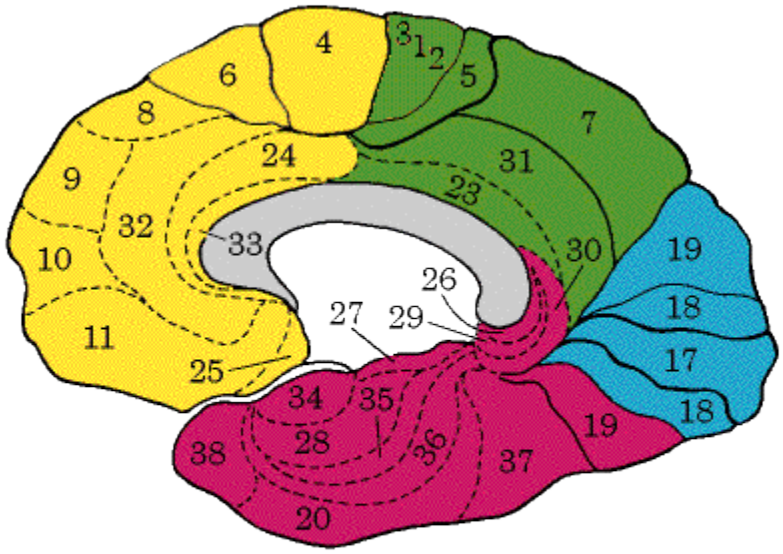

Figure 4.2 Brodmann areas.

German anatomist Korbinian Brodmann published his maps of cortical areas in humans, monkeys, and other species in 1909, but a more detailed map was published by Constantin von Economo and Georg N. Koskinas in 1925.

The Emotive headset is located over 7 of the most prominent of these Brodmann areas, the Dorsolateral prefrontal cortex, frontal eye fields, anterior prefrontal cortex, primary gustatory cortex, middle temporal gyrus, primary motor cortex, and the somatosensory association cortex. These areas are displayed in table 4.2 in relation to their location in the brain, and in table 6.2 referencing which sensors are over which area.

Area Name	Brodmann Area Number
Dorsolateral prefrontal cortex	9
Frontal eye fields	8
Anterior prefrontal cortex	10
Primary gustatory cortex	43 (not show on diagram)
Middle temporal gyrus	21
Primary motor cortex	4
Somatosensory association cortex	7

Table 4.2 Brodmann areas and locations

4.2.1 The Dorsolateral Prefrontal Cortex

Also known as DL-PFC is part of the “primate” part of the brain and actually consists of Brodmann areas 9-12, 45, 46, and 47. It acts as the highest cortical area responsible for organization, motor planning, and regulation. “It is responsible for integration of sensory and mnemonic information and the regulation of intellectual function and action.” It is involved in all complex mental activity but requires the additional cortical circuits that are connected to other regions.

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4.2.2 Frontal Eye Fields

This area is located in the prefrontal cortex which is ultimately connected to the frontal cortex of the primate brain close to the skull. Also referred to as FEF the frontal eye fields control eye movements and visual attention. The area is activated during the initiation of eye movements such a blinking, rapid eye movements, and twitches. There is also evidence to suggest that the FEF plays a role in a purely sensory processing way as well. But together with the supplementary eye fields, the intraparietal sulcus, and the superior colliculus, the FEF controls all eye related movement.

4.2.3 Anterior Prefrontal Cortex

The anterior prefrontal cortex which is part of Brodmann area 10 which also includes the rostral and frontopolar prefrontal cortex, is the largest cytoarchitectonic area in the brain and not much is understood about this region. Best guess is that this area is involved in strategic processes in memory retrieval and executive function. It is proposed that ‘cognitive branching’ occurs here which enables a previously running task to be maintained in a pending state while the task at hand is comleted.

4.2.4 Primary Gustatory Gyrus

One of the least understood areas of the brain. No official information could be found.

4.2.5 Middle Temporal Gyrus

Located on the temporal lobe, the middle temporal gyrus’ exact function is unknown but has been connected with processes ranging from contemplating distance, recognition of known faces, and accessing word meaning while reading. It should be noted that this area is for reference while using the Emotive headset.

4.2.6 Primary Motor Cortex

The primary motor cortex work in unison with the premotor cortex, the supplementary motor area, and posterior parietal cortex to send synapses down the spinal column. It contains large neurons called Betz cells, which send long axons sown the spinal cord. The PMC contains a rough map of the body with different parts of the body controlled by partially overlapping regions of the cortex arranged from toe to mouth.

4.2.7 Somatosensory Association Cortex

Also known as SAC, the somatosensory association cortex has been linked to involvement with speech language and also movement. It has been seen that a reduction in SAC activity is a response to speaking, so the area appears to be activated by simple rather than complex sensory stimuli.

4.3 Reasons for Specific Testing Reactions

4.3.1 Temperature Change

During headset testing method tried to induce difference brain activity was drastically changing the temperature of an extremity. This was thought to produce a different pattern to help control a second action for the 3D cube in the Cognitiv suite in the Emotiv software, which is explained more in section 6 and 11. The guess was that by altering the temperature of a specific body part, a change in brain activity would present itself but to the tester's surprise, it did not.

Temperature responses in the brain are in the preoptic are of the hypothalamus which is in the midbrain tegmentum (split). It has been seen that "a mechanism is initiated to deliver more blood to this region to compensate for the temperature induced drainage of blood out of the brain. A compensatory reaction is generally observed in mammalian brains to supply oxygenated blood to accommodate increased oxygen consumption by cells." (Ogawa et al. 1992)

The problem with this was that the hypothalamus is too far inside the brain to register its activity on Emotivs, sub-medical grade equipment. Therefore no stable or strong response was seen.

4.3.2 Music

Another method tested for trying to induce a different kind of response in the brain was having the user listen to different kinds of music. First off it has been that people like listening to music for the same reason they like eating or having sex. All 3 of those activities release the chemical called dopamine. Had this been researched before testing it could have been deduced just from that statement that music was not a wise choice for stimuli because it has been seen that brain patterns of a person eating or having sex are, while elevated, quite erratic in nature.

Researchers at McGill University in Montreal conducted a study with eight people who consistently felt chills from particular moments in some of their favorite music. PET (positron emission tomography) showed that the participant's brains pumped out a profuse amount of dopamine while listening to favorite pieces of music as opposed to just a slightly elevated amount when listening to other music. "It was seen that dopamine surged in one part of the striatum during the

15 seconds leading up to a thrilling moment, and a different part when that musical highlight finally arrived.”

This information backed up the tests conducted by our group when increased brain activity for specific genres of music showed up compared to others. The fact that this region of the brain is always elevated while listening to music was promising but eventually led nowhere because of the extreme changes in the elevated activity due to the uses specific taste in music.

4.3.3 Pain

The last testing method tried (for obvious reasons) was that of inflicting pain on the user by the insertion of a thumb tack into a shoe and then having the tester put on the shoe.

First off, nociception is what the sensation of pain is called, and while pain seems to be related to the sense of touch, the two register on a completely different neurological level. Once pain is detected its sent to the spinal cord and up to the brain,(it is fascinating to note that the signal crosses over to the opposite side of the spinal cord and then is sent to the brain, so a feeling of pain on the right side of the body is a signal that climbs up the left side of the spinal cord) once in the brain the sense of pain is registered by many areas but most predominantly the somatosensory association cortex.

As stated above in the previous section, the somatosensory cortex is toward the top of the brain and close to the skull which makes is easily detectable by the Emotiv neuroheadset. Once this was seen in testing more was done to provoke a more intense response. It was found that when pain that is induced by tissue damage (i.e. cuts and bruises) the nociceptors become even more sensitive to pain, a phenomenon known as hyperalgesia. When cells are damaged histamine, serotonin, and prostaglandin are released into the area of the injury making the neurons send the sensation to the brain quicker. Ultimately the neurological response is the same, at least for minor injuries.

So because of the Emotiv Neuroheadsets position of sensors O1 and O2 right over the somatosensory association cortex , described more in section 6, the external stimuli was decided on being pain.

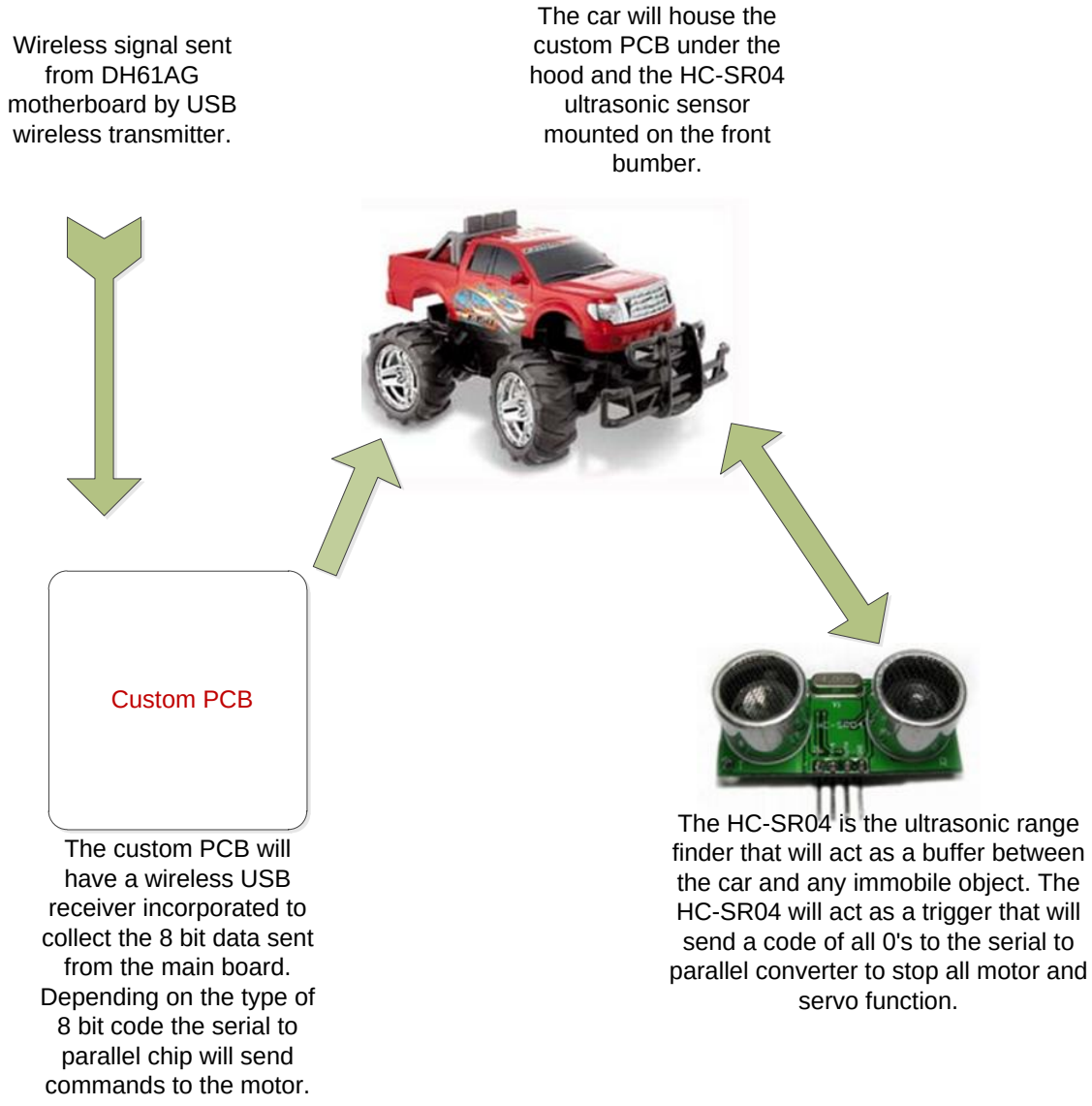
What was more fascinating that the very predominant display that pain had on an EEG, was that the brain started to mimic the pain response on the EEG without any pain being inflicted.

What could be gathered about this phenomenon was that, with the tester having conscious knowledge of how the pain of the tack in the shoe feels, and physically looking at the shoe with the tack in it, the brain knew it was supposed to be registering pain to perform the action on the 3D cube in Emotivs Cognitiv suite. But the tester felt no pain what so ever, the adaptive ability of a trained brain was absolutely remarkable. Regrettably no published paper on this phenomenon could be found.

INFLICTING PERSONAL INJURY WAS NOT DONE FOR CONDUCTING ANY OF THE TESTS PREFORMED.

5. Design Overview

The EPOC-alypse controlled car will have 5 major parts which consist of; the Emotiv EPOC neuroheadset, the Intel DH61AG motherboard, a custom Arduino PCB, custom PCB located on the car, and an ultrasonic sensor array located on the car. All 5 of these components will work together to achieve the ultimate goal of making the car move. Show are 2 flow diagrams(figures 5.1 and 5.2); these are a visual representation of that each component looks like and a summary of what each part does.


Wireless signal sent from DH61AG motherboard by USB wireless transmitter.
The car will house the custom PCB under the hood and the HC-SR04 ultrasonic sensor mounted on the front bumber.
Custom PCB
The custom PCB will have a wireless USB receiver incorporated to collect the 8 bit data sent from the main board. Depending on the type of 8 bit code the serial to parallel chip will send commands to the motor.
The HC-SR04 is the ultrasonic range finder that will act as a buffer between the car and any immobile object. The HC-SR04 will act as a trigger that will send a code of all 0's to the serial to parallel converter to stop all motor and servo function.

(figure 5.1) Flow diagram of how onboard electronics will work

Emotiv Headset gathers EEG information and transmits it via Bluetooth to the DH61AG board

The Bluetooth signal is receive via the Emotiv Bluetooth dongle that plugs into one of the USB ports. This signal is then translated into a string and sent to a custom arduino board.

The custom Arduino board will be connected via USB to the DH61AG and will receive the strings and convert them into 8 bit format needed to move the car. These are then sent back to the DH61AG.

Custom PCB

Once the 8 bit code is back on the mainboard it is sent to the car using a wireless USB receiver/transmitter pair to the car.

Onboard the car will be another custom made PCB what will house the USB receiver and the processor for the car. Depending on the 8 bit code produced by the Arduino, forward, backward, left, or right movement should result.

(Figure 5.2) Flow diagram of how entire system will work.

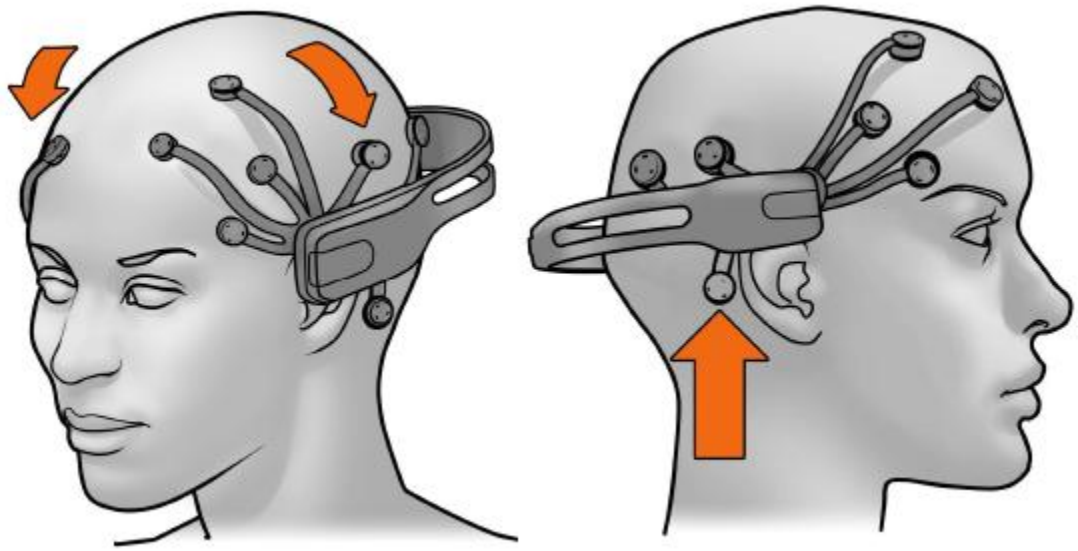
6: Hardware Overview

6.1: Headset

The Emotiv EPOC headset is an affordable easy to use marketed EEG recording device. Targeted at the emerging BCI video games market, Emotiv aims to enhance the gaming experience. Emotiv's design also has attracted the interest of neuroscientists due to the setups low price, running inexpensive experiments from one's own computer.

The Emotiv headset is the key to the entire project, being what obtains and transmits the neuro-signals. The headset comes with 14 independent sensors that consist of felt pads with gold connections to increase the sensitivity of the pickups. These felt sensors need to be moist at all time to conduct the potential difference across the skull, this is done by using a saline solution.

The placement of the headset on ones scalp is also an integral part to the acquisition of signals. As the headset is carefully slipped on it is key that to place the sensors with the black rubber insert on the bone just behind the ear lobe, as shown below in figure X

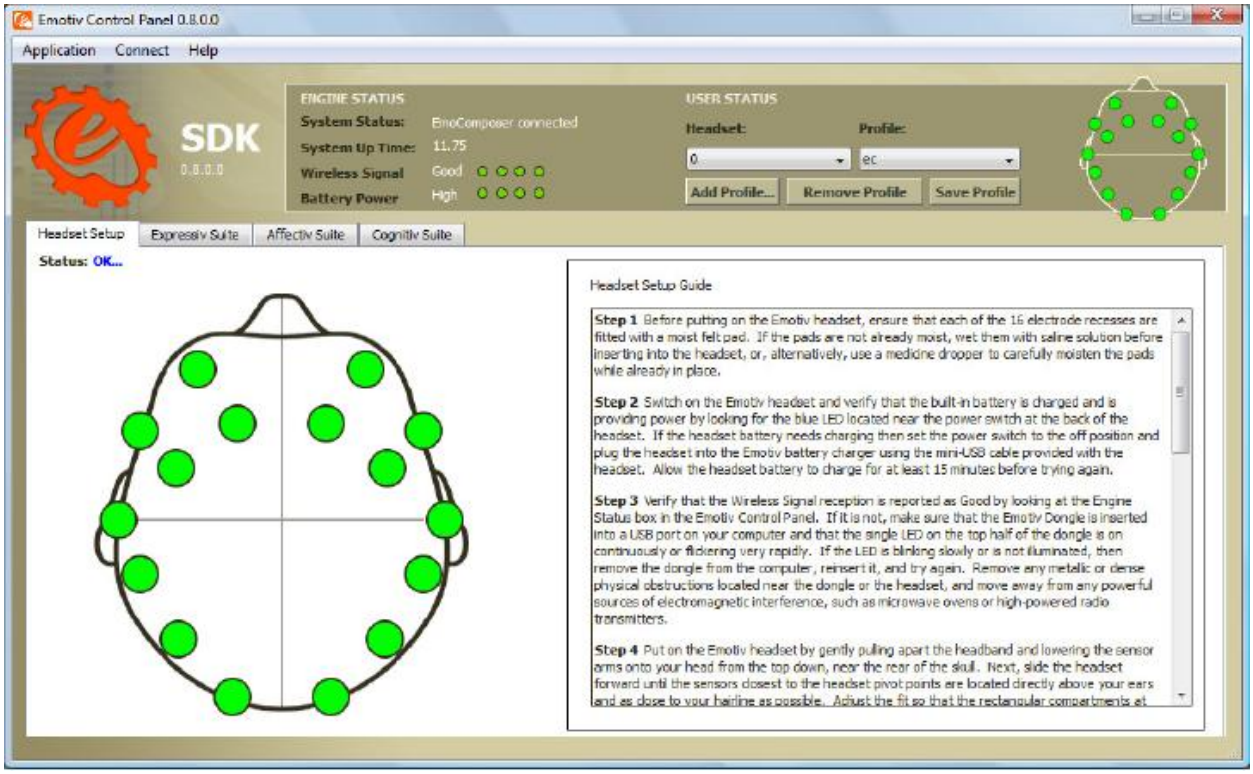


(Figure 6.1) Shows the correct placement of the headset with respect to the rubber reference sensor.

It should be noted that the two front sensors should be approximately at the hairline or three fingers above the eyebrows. After the headset is in position check to see that there is good contact by the reference nodes, this is essential because a bad connection with these sensors will not produce any readings.

Once the headset is connected via the wireless USB receiver the headset setup panel is displayed. The main function of this panel is to display the contact quality feedback for the neuroheadset's EEG sensors.

The EPOC headset has sixteen electrodes to measure the potential difference across the skull. However there is no official reference for the user wearing the headset so the electrodes are actually paired up, and the difference between a pair is used as the measured signal. So when the user is training a certain action to manipulate a 3D cube with the Cognitiv suite, it is comparing how the values of a pair of electrodes change. Therefore whenever it sees a similar change, the software recognizes that you are trying to perform a specific action on the cube.


Emotiv Control Panel 0.8.0.0
Application
Connect
Help
SDK
ENGINE STATUS
System Status:
EmoComposer connected
System Up Time:
11.75
Wireless Signal
Good
Battery Power
High
USER STATUS
Headset:
Profile:
Add Profile...
Remove Profile
Save Profile
Headset Setup
Expressiv Suite
Affectiv Suite
Cognitiv Suite
Status: OK...
Headset Setup Guide
Step 1 Before putting on the Emotiv headset, ensure that each of the 16 electrode recesses are fitted with a moist felt pad. If the pads are not already moist, wet them with saline solution before inserting into the headset, or, alternatively, use a medicine dropper to carefully moisten the pads while already in place.
Step 2 Switch on the Emotiv headset and verify that the built-in battery is charged and is providing power by looking for the blue LED located near the power switch at the back of the headset. If the headset battery needs charging then set the power switch to the off position and plug the headset into the Emotiv battery charger using the mini-USB cable provided with the headset. Allow the headset battery to charge for at least 15 minutes before trying again.
Step 3 Verify that the Wireless Signal reception is reported as Good by looking at the Engine Status box in the Emotiv Control Panel. If it is not, make sure that the Emotiv Dongle is inserted into a USB port on your computer and that the single LED on the top half of the dongle is on continuously or flickering very rapidly. If the LED is blinking slowly or is not illuminated, then remove the dongle from the computer, reinsert it, and try again. Remove any metallic or dense physical obstructions located near the dongle or the headset, and move away from any powerful sources of electromagnetic interference, such as microwave ovens or high-powered radio transmitters.
Step 4 Put on the Emotiv headset by gently pulling apart the headband and lowering the sensor arms onto your head from the top down, near the rear of the skull. Next, slide the headset forward until the sensors closest to the headset pivot points are located directly above your ears and as close to your hairline as possible. Adjust the fit so that the rectangular compartments at

(Figure 6.2) A screenshot of the headset setup panel showing all good connections for all 14 sensors.

This image represents the sensor locations as seen when looking down from above onto the user's head. Each circle represents one sensor and its approximate location when wearing the headset.

Number of channels	14 (plus CMS/DRL references
Channel names	AF3, AF4, F3, F4, F7, F8, FC5, FC6, P3 (CMS), P4 (DRL), P7, P8, T7, T8, O1, O2
Sampling method	Sequential sampling, Single ADC
Sampling rate	128 Hz (2048 Hz internal)
Resolution	16 bits
Bandwidth	0.2 – 45 Hz, digital notch filters at 50 Hz and 60Hz
Dynamic range	256 mVpp
Coupling mode	AC coupled
Connectivity	Proprietary wireless, 2.4 GHz band
Battery type	Li-poly
Battery life	12 hours
Impedance measurement	Contact quality using patented system

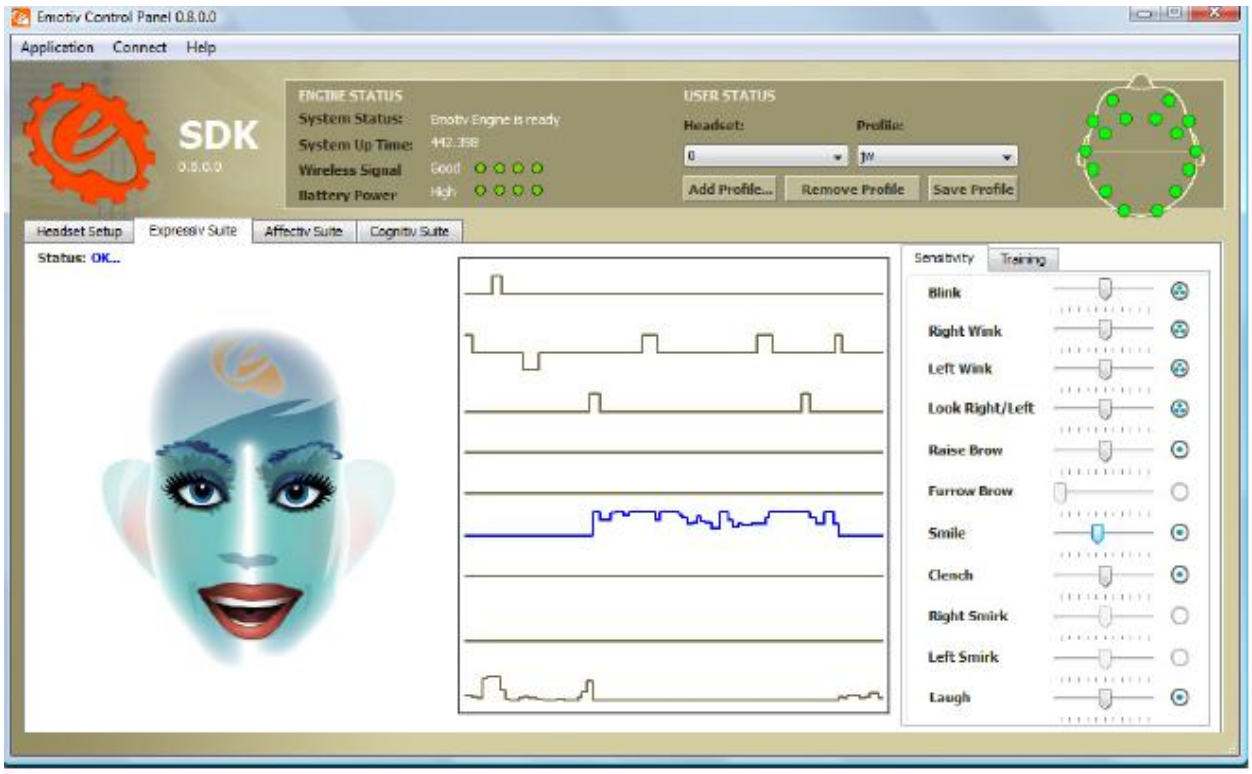
(Table 6.1) Emotiv neuroheadset specs.

Source: Emotiv. Emotiv Software Development Kit User Manual for Release 1.0.0.5.

6.1.1 The Three EMOTIV Acquisition Suites

There are three Emotive acquisition suites; the Expressiv suite, the Affectiv suite, and the Cognitiv suite. Each of these uses a different kind of interpretation of the sensor's signals to display different kinds of reading.

6.1.1.1 The Expressiv Suite



(Figure 6.3) The EXPRESSIV suite control panel.

While in EXPRESSIV suite, the avatar on the left of the screen will actually mimic the user's facial expressions. While at the same time the graphs to the right of the avatar will indicate which of a various amounts of facial expressions are being registered. These graphs show short history of the detections listed, and can be interpreted as follows:

- **Blink**: low level indicates a non-blink state, while a high level indicates a blink.

- **Right Wink / Left Wink**: these two detections share a common graph line. A center level indicates no wink, low level indicates a left wink and high level indicates a right wink.

- **Look Right / Left**: these two detections share a common graph line and a single sensitivity slider control. A center level indicates eyes looking straight ahead, while a low level indicates eyes looking left, and a high level indicates eyes looking right.

- **Raise Brow:** low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.

- **Furrow Brow**: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.

- **Smile**: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.

- **Clench**: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.

- **Right Smirk / Left Smirk**: these two detections share a common graph line. A center level indicates no smirk, low level indicates a left smirk and high level indicates a right smirk.

- **Laugh**: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.

This control panel also includes sensitivity adjustments by moving the sliders on the right for each of the corresponding graphs.

EXPRESSIV supports 2 types of signatures that are used to classify input from the headset as indicating a particular facial expression, a preprogrammed universal signature or a trained signature. The foremost being what the average readings for blink, wink, etc. would be and the latter being the use performs an action, such as blink, and the program remembers it for future use.

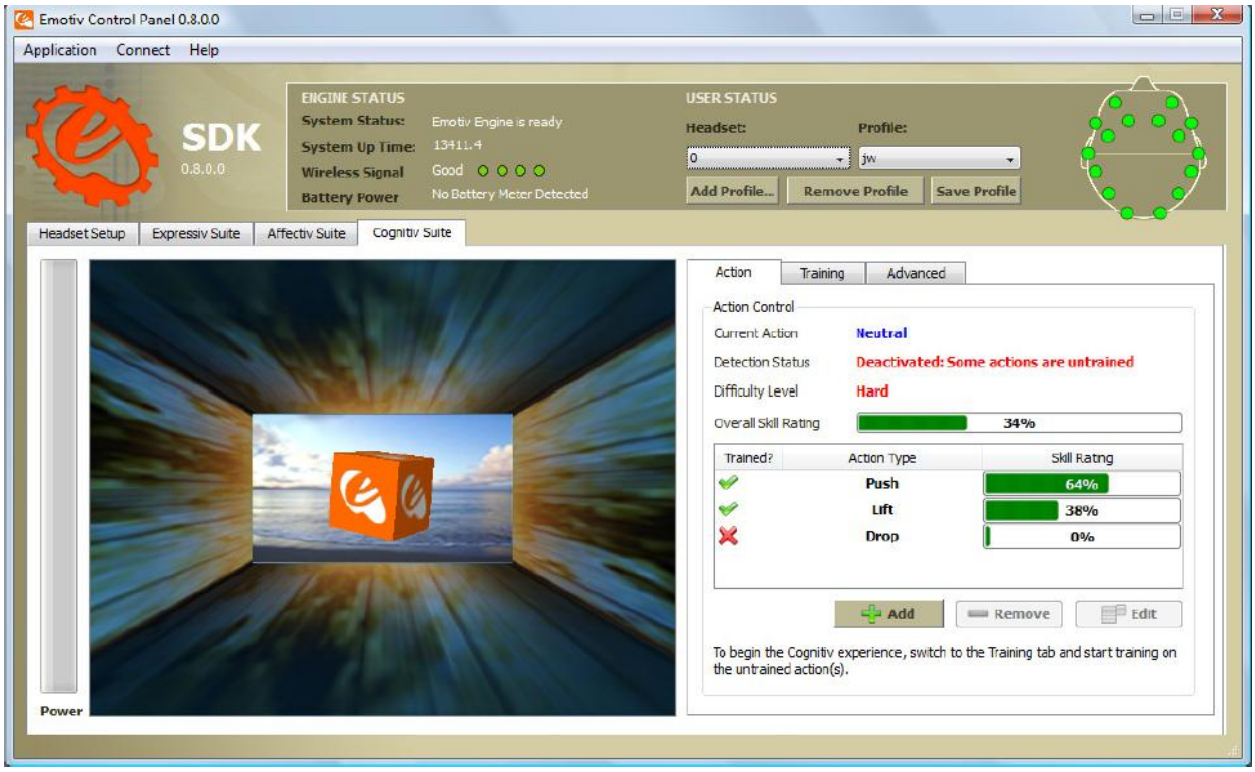
6.1.1.2 The Cognitiv Suite

This suite detects and evaluates a user's real time brainwave activity to discern the user's conscious intent to perform distinct physical actions on a real or virtual object. The detection so designed to work with up to 13 different actions including directional movements and rotational movements and an extra action that exists only in the users imagination which is to make something disappear.

The suite allows the user to choose up to four actions that can be recognized at any given time. The detection reports a single action or neutral, which would be no activity at a time, along with an action power which represents the detections certainty that the user has entered the cognitive state associated with that action.

The tricky part being that increasing the number of concurrent actions increases the difficulty in maintaining conscious control over the Cognitiv detection results. This is where training would come into play. New users gain control over a single action quite quickly but learning to control multiple actions requires practice and adding more actions quickly increases the difficulty,

The Cognitiv suite control panel uses a virtual #D cube to display an animated representation of the detection output. This cube is used to assist the user in visualizing the intended action during the training process. In order to enable the detection, each chosen action, plus the neutral action, must be trained. The suite enables the EmoEngine to analyze the uses brainwaves and develop a personalized signature which corresponds to each particular action as well as the background state of neutral. As the engine refines the signatures for each of the actions, detections become more precise and easier to perform.



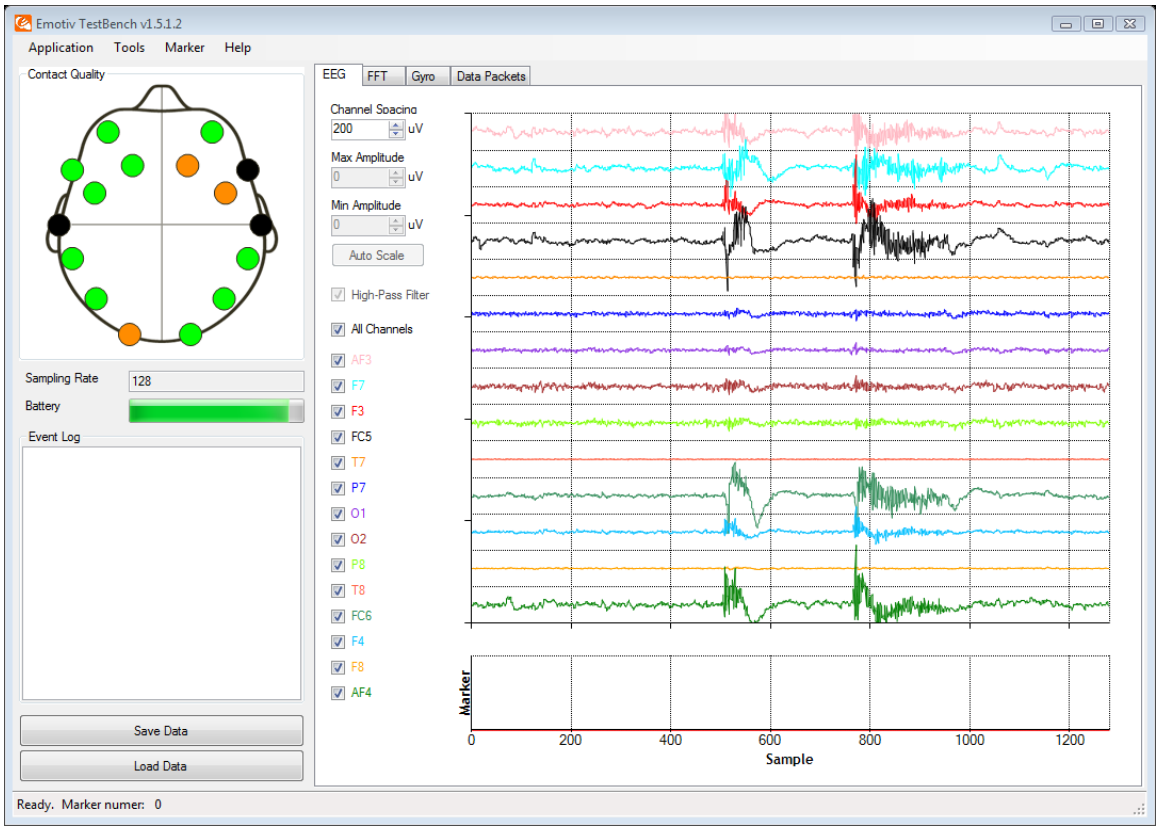
(Figure 6.4) the Cognitiv control panel with interactive 3D cube to simulate the action that the user is intending to accomplish.

6.1.1.3 The Test Bench

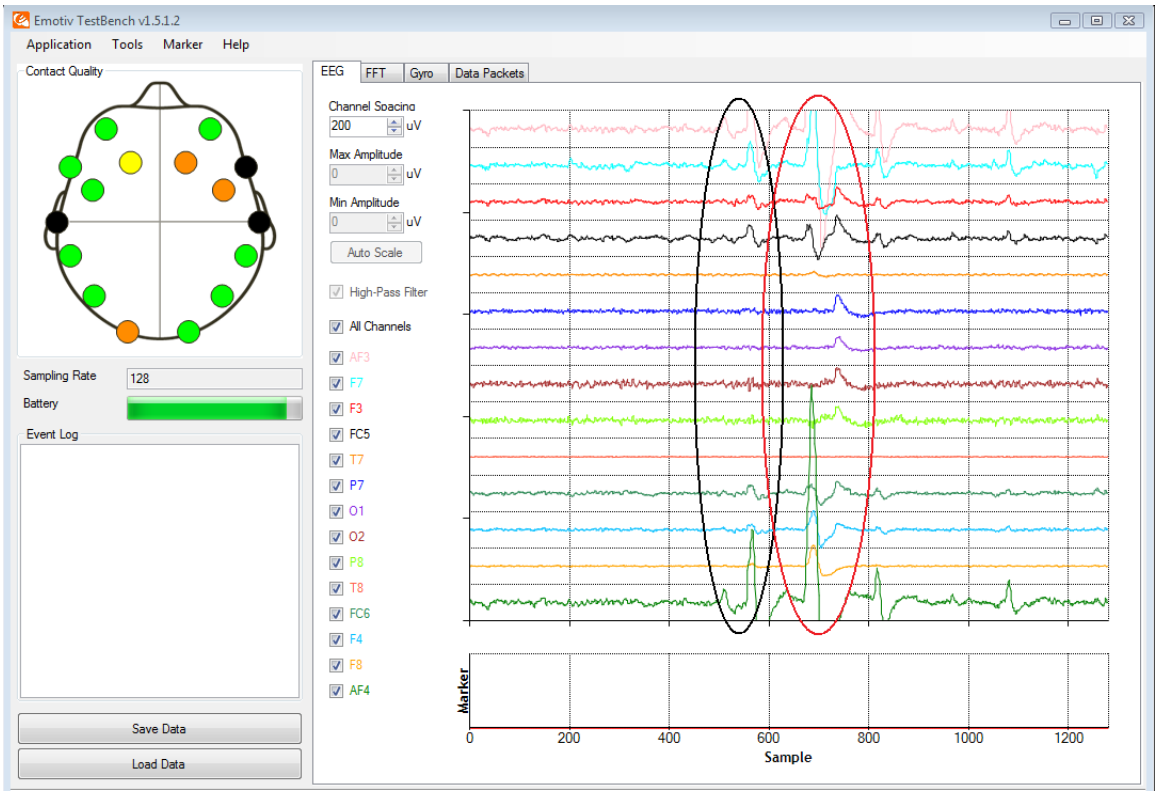
The Test Bench software is a real time EEG reading that displays the output of all 16 sensors. It can be noted early on that facial expressions such as blinking, smiling, and teeth clenching, are all very discernible due to the fact that the brain activity that is signaling these actions is very close to the top of the skull.

It is from the test bench that it can be seen where the increase in brain activity is coming from for training the Cognitive actions for the car. By being able to see the level of activity in a specific area of the brain, it is much easier to isolate ones thoughts and learn to activate the region on demand.

The figures below illustrate a few of the most noticeable readings from a few facial expressions. Though the sensitivity of the headset limits the detection of thoughts that can affect the Cognitive suite in manipulating the 3D cube.



(Figure 6.5) This is the EEG reading from clenched teeth. The active areas are areas that are toward the front of the head. The short spike is from a short clench and the longer one is from prolonged clenching.

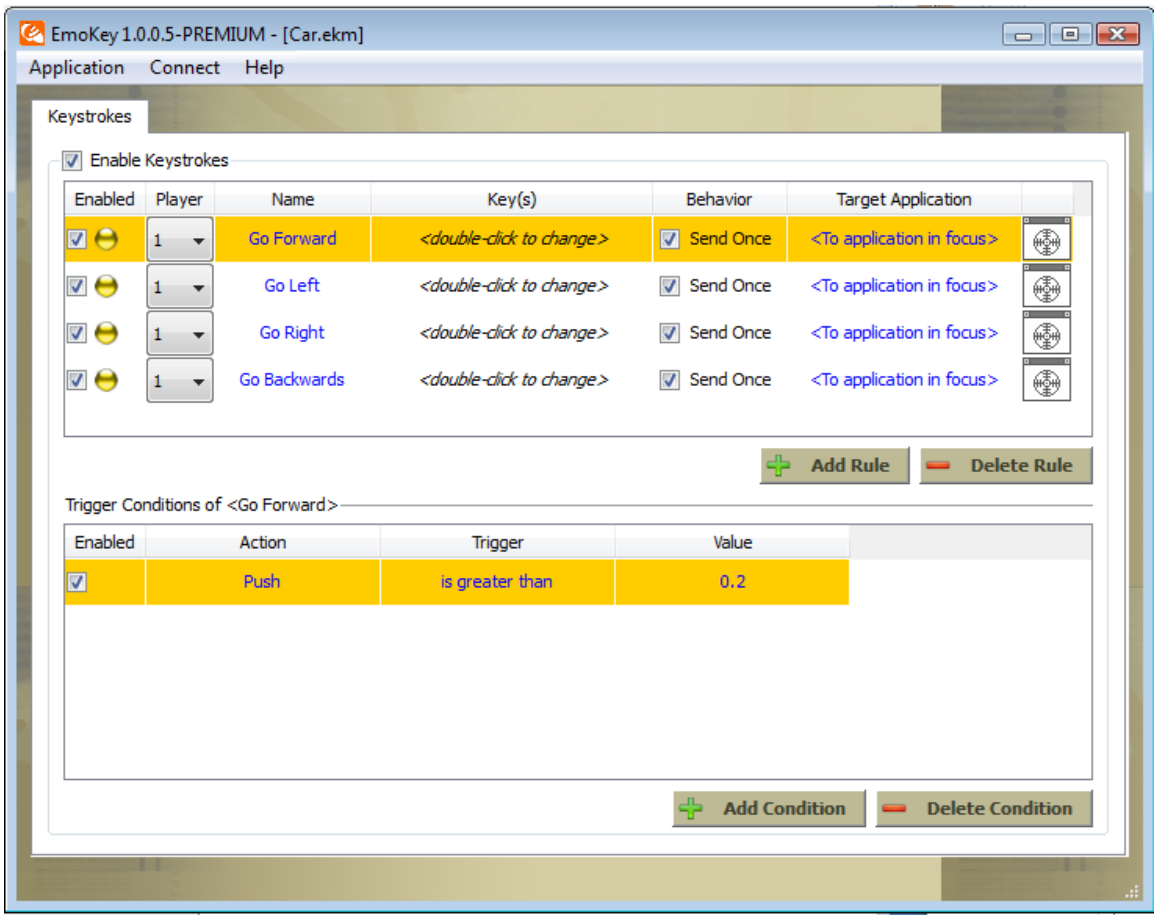


(Figure 6.6) Here, blinking is shown. The spikes in the black circle reflect a normal blink while the spikes in the red circle reflect a much harder and intense blink.

6.1.1.4 Emokey

For our project we will be combining both the Expressiv suite and the Cognitive suite. Using the Expressiv suite's facial cue detection to control lateral movement (left and right) and using the Cognitiv suite to control forward and backward movement. By winking with ones left eye the car will turn left and by winking the right the car will turn right. And by using the Cognitiv "push" and "pull" actions for the 3D cube, we will associate the push action with forward movement and the pull action with reverse.

To convey these instructions from the motherboard to the arduino board the Emokey program will be used. Emokey maps out routes for instructions by associating a specific action with a command. The figure below shows a preliminary mapping for the car. The commands forward, backward, left, and right are triggered by push, rotate right, wink left, and wink right respectively. For instance with the push command, the Emokey will translate the push events generated by the Cognitiv suite into forward motion as long as the Cognitive suites push detection is reporting a score > 0.2



(Figure 6.7) Emokey mapping for controlling the car.

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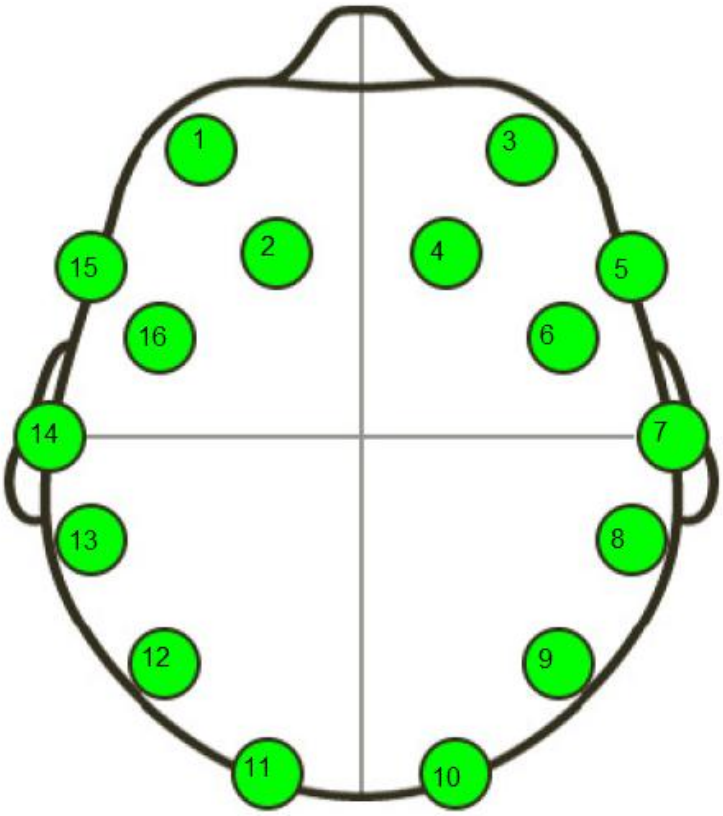
6.1.2 Headset Configuration

There are 16 different sensors on the headset that correspond to 7 different areas of the brain as shown in figure 6.8. These sensors are arranged into 7 pairs; AF3 and AF4, F3 and F4, F7 and F8, FC5 and FC6, T7 and T8, P7 and P8, O1 and O2, and DRL and CMS which are reference nodes.



(Figure 6.8) Sensor layout as viewed from the top of the skull.

Sensor Number	Sensor Name	Region of Brain Sensor is Located Over
1	AF3	Dorsolateral prefrontal cortex
2	F3	Frontal eye fields
3	AF4	Dorsolateral prefrontal cortex
4	F4	Frontal eye fields
5	F8	Anterior prefrontal cortex
6	FC6	Dorsolateral prefrontal cortex
7	T8	Primary gustatory cortex
8	DRL (reference)	Middle temporal gyrus
9	P8	Primary motor cortex
10	O2	Somatosensory association cortex
11	O1	Somatosensory association cortex
12	P7	Primary motor cortex
13	CMS (reference)	Middle temporal gyrus
14	T7	Primary gustatory cortex
15	F7	Anterior prefrontal cortex
16	FC5	Dorsolateral prefrontal cortex

(Table 6.2) Sensor names and relative locations.

6.1.3 Headset Transmission

The headset actually transmits over Bluetooth and Bluetooth dongle, the Emokit gets a connection to the Bluetooth device using a standard HID interface. Once the connection is made it gets 32 byte reports from the device that are encrypted to the Emokey language, these are then decrypted by using AES. The Emokit then parses out the gyroscope data and the actual sensor data and sends it to a queue that can be read in whichever manner is desired.

(Figure 6.9) Emotiv USB Bluetooth receiver.

6.2: The car

The vehicle that will be used will preferably be small in size but it can range in size from 6” in height to 12” in height. Although a smaller vehicle is preferred, it cannot be too small as it will need to house multiple pieces of hardware on it in order for it to function as intended. The vehicle will need to house:

- one proximity sensor
- a DC drive motor
- a DC servo motor
- several batteries
- many small DC voltage regulators ranging between 5 and 10 volts
- serial to parallel converter
- receiver between the motherboard and the vehicle

A small Remote control vehicle will be used as a base that includes some of these components but there will be a printed circuit board that will be created to hold the rest of the parts needed for this project.

The proximity sensor will be placed on the front of the vehicle using a small bracket or clip. The sensor will be used to ensure that no damage will be done to the vehicle due to hitting or bumping into other objects. The sensor should be small enough to be housed on the vehicle without interfering with other components and without being interfered with itself. It will preferably be a capacitive sensor that will be able to detect metallic and non-metallic objects such as liquids, plastics, or woods from a distance of 35 cm to 1 m. Otherwise it will be an inductive sensor that can only detect metallic objects from the same distances.

A lightweight DC drive motor with an operating voltage of 6 volts will be used to move the vehicle, the motor has a two wire connection where all the power for the motor used in the vehicle is delivered between the two wires from the battery. For the purposes of this project, the DC motor should have a maximum spin of at least a few thousand RPM’s. The driving force of the vehicle will be a variable DC voltage that is small and light enough to fit on the back of the vehicle and does not interfere with the performance. The variable DC voltage will preferably be in the range of 0-9 volts which should be strong enough to move the vehicle at an acceptable speed.

The DC servo motor is the assembly of a normal DC motor, a gear reduction unit, a position-sensing device, and a control circuit. The servo motor receives a control signal that represents a desired position of the servo shaft, in turn power is applied to the DC motor in the servo motor and it rotates within 200 degrees back and forth until the shaft is in that position. The servo motor has a three wire connection respectively, the power, ground, and control wires. The power wire must have a 5 volt high current power source constantly applied to it for it to function properly.

The two batteries that will be used to power the vehicle will be at least 12 volts each in order to properly power the DC motor and the motherboard. In addition to these requirements, the batteries will need to be at least 1000mA/H in order to give an adequate amount of time to test the vehicles operation.

Voltage regulators will be used in order to properly power the serial to parallel converter, the DC drive motor, and the DC servo motors. This will be done by maintaining a constant voltage level so as to avoid any damage to the processor in any way. One of the voltage regulators will control the DC servo motor to change in the range of 0 to 5 volts to determine the extent of which the vehicle will turn. The other voltage regulators will control the DC drive motor and the serial to parallel converter.

There will need to be a system designed to control both the DC drive motor and the DC servo motor. The most simple way to adequately control each of the motors is to use an eight bit serial to parallel converter. This converter will be needed to control the circuit for the DC drive motor.

The chosen motherboard will need to have a processor with an operating frequency of at least 2.4GHz and 1Gb of random access memory, (RAM) and also have at least two USB ports so that the transceiver can be inserted as well as a mouse so that the programming can be done. The motherboard will be used to connect the USB transceiver and run the EMOTIV software as well as the wireless transmitter used to connect to the printed circuit board on the vehicle.

The USB transceiver will receive the information from the headset which in turn will be sent to the written program and used to control specific actions on the vehicle. For instance, when a certain brain wave or facial movement is recognized, that in turn will be linked to an action to move the vehicle in the forward, backward, left, or right directions. This will in turn be sent via the wireless transmitter to the vehicle to be used to control the various actions. The

transmitter operates at a frequency that is free to use, 2.4 GHz, as to not violate any laws instituted by the FCC.

6.3 The Motherboard

In order to run the Emotiv SDK as well as the developed software for this project, a motherboard or mainboard will be used which will be wirelessly connected to the headset as well as the car. While searching for a correct board, there were many specifications that needed to be considered. The Emotiv software has a few minimum requirements that we had to fulfill with our motherboard and processor. First of all, the processor needed to have a clock rate of at least 2.4 GHz. This meant that we had to look for more modern processors that had higher clock rates and more processing power. We also needed to find one that had at least 1 GB of ram and 50 MB of disk space. This was much easier to find, due to the large availability of memory with modern technology. These specifications, as well as price, were the most prominent requirements we needed to find in our motherboard.

After finding many suitable boards for our project, we decided to use the Intel DH61AG Core i3/i5/i7 Desktop Thin Mini-ITX Motherboard. This motherboard has many of the specifications we need for our project as well as a few others that will make the project easier to implement. Some of the more important specifications for this board were:

- 2.5 GHz processor clock speed
- 2 GB Memory
- Expansion slots for PCI Express
- 10 USB ports
- 1 HDMI port

These features of the motherboard will make it easier to not only run the Emotiv SDK and the developed C++ software, but the HDMI port will also allow us to connect it to a monitor and view the Emotiv GUI while running the Emotiv software. One problem we did find with the motherboard was that it did not include a significant amount of disk space, which meant we needed to find an external source of space. In order to make up for this, we found the Emphase Industrial - S1 SATA Flash Module 2 GB. We decided on this module because the motherboard we are using has SATA connections which can be used for storage. This flash module has enough memory to be able to handle the Emotiv SDK as well as the developed software we are writing for the project.

7: Hardware Design

7.1: Headset Hardware Design Overview

The hardware for the project will consist of four components; the Emotiv neuroheadset, the Intel DH61AG core i3 desktop thin mini-ITX motherboard, a custom built Arduino PCB, and a remote controlled car.

7.1.1 Emotiv Neuroheadset

The Emotive neuroheadset, as described in the overview, is an array of 7 sensor pairs, 14 sensors total arranged mostly towards the front of the skull. These sensors measure the dissimilarity between a pair and this difference is recorded as the signal. The signal is then transmitted via blue tooth to the receiver which is plugged into the DH61AG motherboard.

7.1.2 DH61AG Motherboard

The DH61AG core i3 mini-ITX motherboard is a second generation Intel core platform with integrated HD graphics, HDMI, and onboard DC power. It features the 2-chip Huron River platform which is capable of supporting Intel's Core i3/i5/i7 (sandy bridge) processors. The exact processor that has been chosen is the Intel core i3-2100T Sandy Bridge LGA1155 that runs are 2.5 GHz which is perfect for that task at hand.

7.1.2.1 Intel Core i3-3220

With the i3-3220, one gets only two physical cores, but the 3220 features hyper threading which adds an additional two virtual cores. This makes a sizeable difference in performance over the Pentium models. Due to budget constraints, the 3220 does lack turbo boost, thought, with its frequency limited to 2.5 GHz it supports a cache configuration of 2x 256 KB of level 2 cache, 3MB of level 3.

7.2: Vehicle Hardware Design

7.2.1: Battery and Power

In order for the vehicle and all the components on it to be properly powered, there were many things taken into consideration. One of which is what is the total amount of voltage necessary for all the components being used on the vehicle to function as required. After looking at the requirements for each of the components being used, at least two 12 volt rechargeable battery packs will be used. Rechargeable battery packs offer many benefits that regular non rechargeable batteries do not offer. One of which being that they can often last up to five times longer on each charge and are environmentally friendly.

There are many different types of batteries available that can be used for this project. Many modern batteries use a variety of chemicals to power the reactions that ultimately make the batteries work. There are Zinc Carbon, Alkaline, Lithium Ion, Nickel Metal Hydride, and Nickel Cadmium, and Lead Acid. Zinc Carbon batteries are very common in cheap AAA, AA, C, and D dry cell batteries. Alkaline batteries are also very common in AA, C, and D dry cell batteries and gets its name from the potassium hydroxide electrolyte. The lithium Ion rechargeable battery is used in high performance devices such as cell phones and digital cameras and Lead Acid rechargeable batteries is the last type and is most commonly used in car batteries.

Focusing on the rechargeable batteries, the most commonly used is the Lithium Ion battery. These are the most popularly used on the market for many reasons. One of which being the fact that they hold their charge long term . It only loses about 5 percent of its charge per month. Another benefit of this type of battery is that it has no memory effect. In essence, this means that it is not necessary to fully discharge the battery before recharging. Lithium Ion batteries can also be used several hundreds of charging and discharging cycles without loss of use. There are a few disadvantages to these types of batteries though. Once they are fabricated, they only last between two to three years whether they have been in use or not. They are also extremely heat sensitive. If they are in an environment where there are high temperatures, the Lithium Ion battery packs will degrade much faster.

Nickel Cadmium batteries were one of the first rechargeable batteries available on the market. One of the greatest disadvantages to its use is the problem known as the memory effect. In order for the battery to not lose its capacity, it needs to be fully discharged every single time. This is when Nickel Metal Hydride batteries came into favor. These batteries have a higher capacity in comparison and are only minimally affected by the memory effect.

After much consideration, the two chosen 12 volt battery packs used will be Nickel Metal Hydride (NiMH) with at least 1000mA/H to allow for adequate time to test the vehicle and all components involved. Nickel Metal Hydride was chosen because the batteries start out around 1.2 volts, but as it discharges it drops only to about 1.1 volts before the battery is fully depleted. Even though the NiMH battery starts at a lower voltage it provides a more usable voltage for a longer duration of time. It also has a 30 to 40 percent higher capacity over a standard Nickel Cadmium (NiCd) battery and are simple and easy to store and transport. The current ratings of the batteries is very important as to have at least 30 to 40 minutes of drive time while powering both the serial to parallel converter as well as all the vehicle components.

The dimensions of the batteries will most likely be .5” x 3.8” x 2.8” because it will technically be four AA batteries connected together in each battery pack. The two battery packs will be connected in series with the common node of the circuit being that of where the positive of one battery meets the negative of another. Many of the components in the vehicle will be run off of the positive terminal of the batteries, so this in turn requires that the drive and servo motors will be run off of the negative terminals. This will make it so that the other connected components will still remain active when the battery that controls the vehicle has been depleted.

It is also extremely necessary for there to be several voltage regulators in place in order to control the various voltages that are needed to be supplied to each circuit component. Voltage regulators are designed to regulate a constant voltage level to all components involved. Since all of the components need between 5 and 12 volts to properly work, the LM7805 voltage regulator will be used. See figure 7.2.

Figure 7.2

The LM7805 features a simple three terminal regulator with 5,12, and 15 volt regulator options. It also includes internal thermal overload protection so as to prevent damage to the component, due to overheating. With adequate heat sinking the LM7805 can provide up to 1.5A of output current within the temperature range of 0 to 125 degrees Celsius. Three separate voltage regulators with different output supply voltages will be used to power all of the subsystems needed to fully operate the project.

7.2.2: Sensors

In order to preserve the condition of the vehicle and to prevent any damage to it due to foreign objects, one proximity sensor will be used on its front side. This sensor will take information and relay it to the processor, where it can in turn determine how to adjust its position accordingly. The proximity sensor will need to be small in size and relatively inexpensive. There are many different types of sensors, each with their own pros and cons. There are inductive, capacitive, photoelectric, and ultrasonic sensors available.

Inductive proximity sensors are becoming more widely used in detection, positioning, and counting of ferrous and nonferrous metal substances. They can also detect metal through a layer of non metal material. The sensor itself is comprised of an oscillator circuit, which is the actual sensing part, and an output circuit with a switching device that is completely housed in a resin encapsulated body.

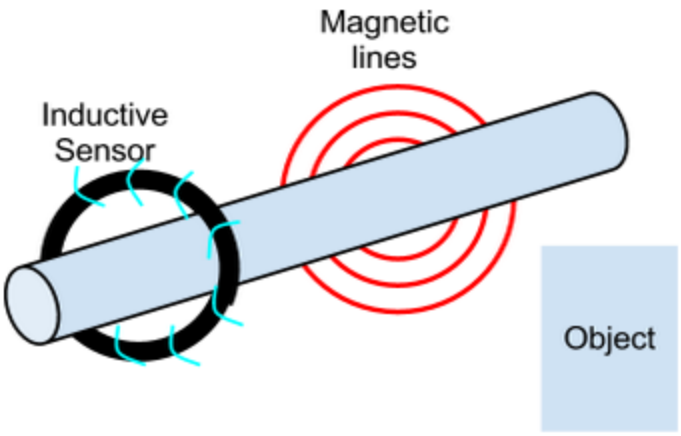


Figure 7.2.1
Inductive Sensor

The way that the inductive sensor actually works is when the inductance coil that creates a magnetic field is disturbed, the circuit responds by closing the output switch. The magnetic field is created on the front of the sensing face and is the essential part in making the sensor work properly.

Capacitive proximity sensors are usually used as a last resort when all other sensing techniques can not be used. They operate by responding to a change in the “dielectric medium surrounding the active face and can thus be tuned to sense almost any substance”. They can respond to all substances that have a high dielectric constant, such as water, oil, fuel, or sugar.

Another benefit to using capacitive sensors is that they can sense a substance through a layer of glass, plastic, or thin carton as well. These sensors are most often used in level control of non conductive liquids, granular substances, or sensing objects through a protective layer such as glass. A disadvantage of using the capacitive sensors is the fact that deposits of excessive dust and dirt on or around the sensing face can cause an erratic response and causes a need of periodic cleaning.

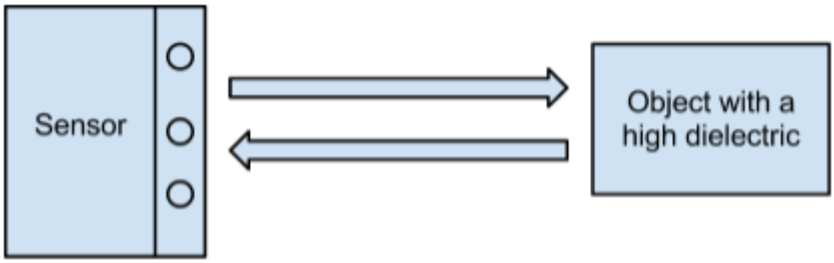


Figure 7.2.2
Capacitive Sensor

The way that capacitive sensors actually work is based on an internal oscillator with two capacitive plate electrodes. These are then tuned to respond when a substance with a high dielectric is approaching the sensors face. If an object is sensed, the output switch will then either close to activate a load for a normally open option, or open for a normally closed option. After all of this has happened, the LED light on the sensor will then illuminate indicating the the switch has made a change.

Photoelectric sensors offer many benefits that other sensors do not. They have non contact sensing of almost any substance or object up to a range of 10 meters. Photoelectric sensors function by using a light source, usually a light emitting diode in infrared or visible light spectrum.

A huge advantage that photoelectric sensors have over capacitive sensors is that these can operate better under dusty or dirty environments. These are also often used because of the focused beam and long range which helps in sensing distance and accuracy. There are many different types of photoelectric proximity sensors. Of these types there are infrared proximity (diffused reflective), transmitted beam (through beam), retroreflective (reflex), polarized retroreflective (polarized reflex), fiber optic, and background rejection. The infrared proximity sensor works by detecting light reflected by the intended target. This type of sensor is most commonly used when the object that needs to be detected is only accessible from one direction.

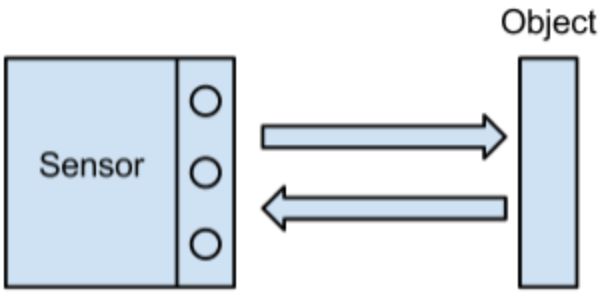


Figure 7.2.3
Diffused Reflective

Another type of sensor is the transmitted beam photoelectric sensor. This uses separate infrared transmitters and receivers so that when an object passes through the infrared beam, it causes the receiver to output a signal. This signal either closes a normally open switch, or opens a normally closed switch.

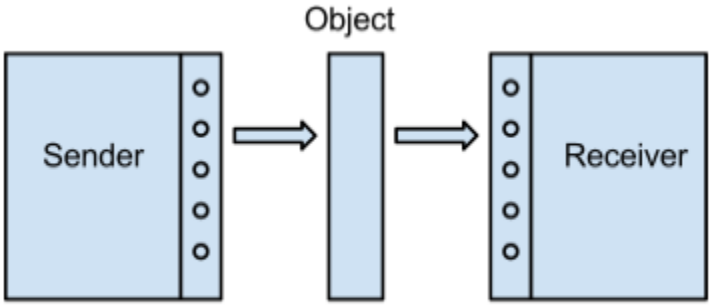


Figure 7.2.4
Through beam

The next type of sensor is the retroreflective photoelectric sensor. These types of sensors operate by sensing the light beam that is reflected back from a target reflector. Just like the transmitted beam sensor, if an object interrupts the beam, an electronic output is activated. Polarized retroreflective sensors work almost the same as retroreflective sensors. The only difference being that it uses a polarizing filter, designed so that shiny objects are easily detectible, in front of the transmitter and receiver optics.

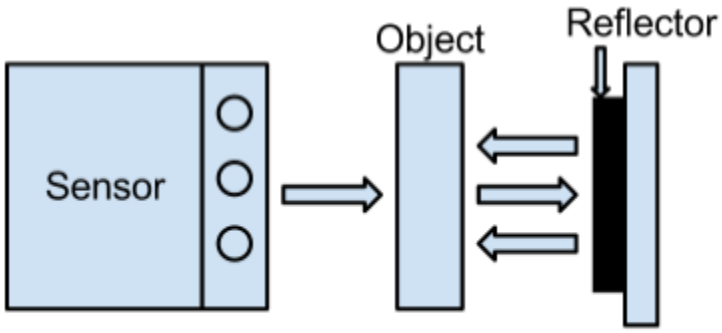
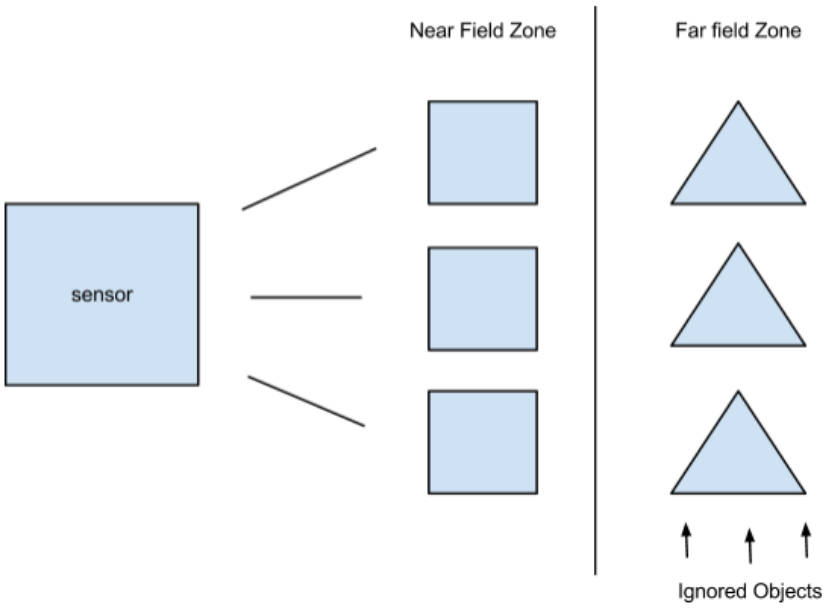


Figure 7.2.5
Retroreflective

The next type of sensor is the fiber optic sensor. These operate like the name indicates, by using fiber optic cables to conduct light from the light emitting diode to the sensing area. Then another cable is used to return the light from the sensing area to the receiver. This type of sensor offers great benefits for sensing in extreme conditions as well as confined spaces. For instance if the sensor is used in an environment that has temperature extremes or is exposed to harsh chemicals, it can still be protected and work properly.

The last type of sensor is the background rejection sensor. This sensor uses a special arrangement of two sensing zones, the near field zone and the far field zone. The near field zone is the area where objects can be detected. The far field zone is the area where objects cannot be detected.



The cut off between these zones is very sharp and extremely precise, although this range is adjustable to meet certain needs. These sensors are mostly used for applications where the objects after a certain range need to be ignored.

Ultrasonic sensors are very useful in detecting objects of different sizes and materials. They work by using the reflection of high frequency sound waves to detect parts of the distances to those parts. There are two basic types of ultrasonic sensors, electrostatic and piezoelectric. The electrostatic sensor uses capacitive effects for longer range sensing and a wider bandwidth with greater sensitivity.

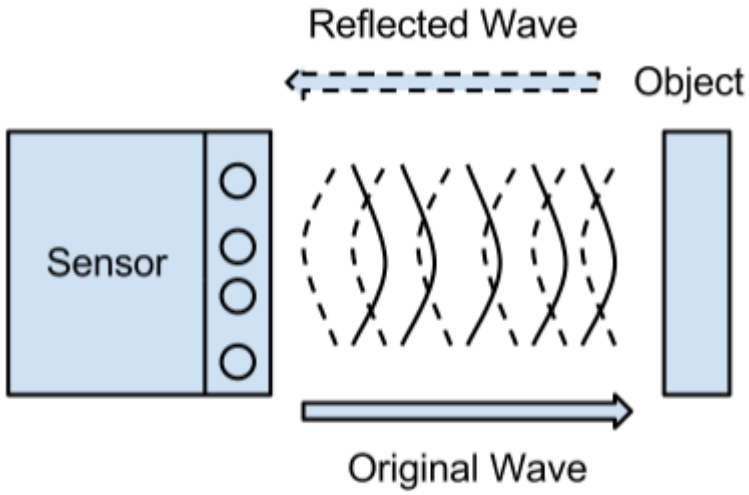


Figure 7.2.6
Ultrasonic Sensor

The piezoelectric sensor is a little more rugged looking and more inexpensive in comparison to other sensors and operates by using a charge displacement during the strain in crystal lattices. When it is necessary to detect transparent objects, such as a clear plastic, the ultrasonic sensor is the best choice in doing so.

After reviewing all of the different types of sensors and the pricing of each, the chosen product for the proximity sensor on the vehicle is the piezoelectric ultrasonic sensor. This was chosen because of its ability to sense any object with varying transparency as well as it being weatherproof and able to function in environments with high humidity, such as that of Florida. The particular chosen model is the Ultrasonic ranging module: HC-SR04.

Figure 7.2.7

This particular component is available for purchase from the iteadstudio website. It only requires a 5 volt DC power supply which works out perfectly with all of the other components on the vehicle. It has a large sensing distance of 2 centimeters to 500 centimeters. This ends up being a little over 16 feet which is more than enough sensing distance required for the scope of this project. In addition to this, the sensor also has a rectangular size of 20 millimeters by 40 millimeters. This fits in perfectly with the size of the chosen remote controlled vehicle as to not hinder its mobility in any way.

The chosen ultrasonic sensor has many capabilities useful to this project. If no output is detected it sends a 38 millisecond high level signal. This will allow the vehicle to keep operating without any due changes. It has a very large mean time to failure of 50,000 hours which should be more than sufficient enough for the scope of this project. It can also operate in the temperature range of -40 to +80 degrees Celsius, which ends up being up to 176 degrees Fahrenheit. It can detect objects up to 5 meters away and has a minimum detection range of 2 centimeters, in the range of 15 degrees in front of the sensor. It also sports a good resolution of .3 centimeters.

7.2.3: RC Car and Accessories

To begin conceptualization of the vehicle and its various accessories, it is necessary to choose a remote controlled car early on. The vehicle chosen for this project is the “EZTEC Ford F-150”. This vehicle was primarily chosen for its being large enough to house all the extra components that are necessary to be added without interfering with its mobility and its being perfectly within our price range. The vehicle has a 1:19 scale ratio with dimensions of 5.8 inches tall, 6.1 inches wide, and 10 inches long. It weighs approximately 1.5 pounds which is lightweight and allows for other components to be added without hindering the maneuverability of the vehicle. It also has a great low cost of $20, which fits in nicely with our budget.

Figure 7.2.8

The servo motor that is inside of the vehicle will be exchanged for one with a better angular movement. The chosen servo is the “Hitec 31055S HS-55 Economy Sub Micro Universal Servo”.

Figure 7.2.9

This servo is a lot more reliable in comparison to other servo motors in this reasonable price range. It comes out to being $11 with free shipping which fits in nicely with our vehicles budget. It has an input range of operation at 4.8 to 6 volts which also coincides acceptably with the output voltage of the LM7805 voltage regulator. In addition, it has a motor speed of 438 degrees per second, which is about 73 revolutions per minute (RPM). This high speed of motion is more than

adequate for the purpose of this project, especially because the drive motor has a maximum angular displacement of 40 degrees.

The drive motor in the vehicle will need to be replaced because the current speed of the vehicle with its current motor is unacceptable. After much consideration, the “Mabuchi RS-380 Brushed DC Motor” has been chosen.

Figure 7.2.10

The motor operates between 3 and 6 volts with a nominal voltage of 6 volts. It has a no load current of .8mA with a no load speed of 18000 RPM and a light weight of 71g. The motor as well has a stall torque of 771 g/cm with a stall current of 24A. For the purposes of this project, those values should never be reached. To ensure this, a 15A fuse will be placed on the voltage input in order to prevent damage to the components.

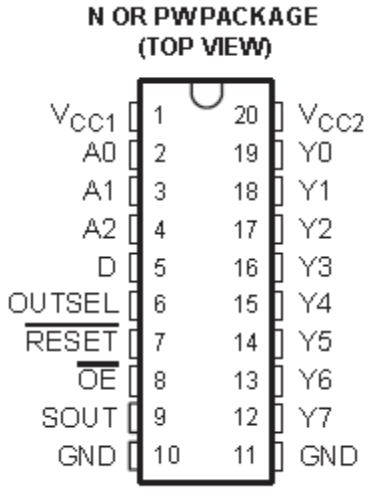
7.2.4 DC drive and servo motors control

The DC drive motor creates somewhat of a complicated situation pertaining to the hardware design of the vehicle. There will need to be a system designed to control both the DC drive motor and the DC servo motor. The most simple way to adequately control each of the motors is to use an eight bit serial to parallel converter. The converter will need to be used to control the circuit for the DC drive motor. The part that will be used to accomplish this task is the 74LV8153N and it is produced by Texas Instruments.

Figure 7.2.11

This specific part offers an automatic data rate detection feature. This eliminates the need for an external oscillator and helps lower the cost significantly. Up to eight devices can share the same bus by using different combinations of A0, A1, and A2. Power supply levels are referenced to Vcc1 and Vcc2 and can be configured from 3 volts to 5.5 volts and 3 volts to 12 volts respectively.

Figure 7.2.12



Vcc1 is the power supply pin for all inputs and outputs except Y0-Y7. Vcc2 is the power supply pin for the outputs Y0-Y7. It has a maximum data rate of 24 kbps, which is more than satisfactory for the scope of this design. The physical size of this part is .775 inches in length and .5 inches in width, with a height of about .2 inches

Since the DC drive motor that was chosen operates at 6 volts, it is necessary to create a circuit that has an output of 6 volts as well. This will help to get the most out of the motor itself. To begin, the input to the circuit would need to be a parallel binary signal that will come from the processor. This will need to be

realized via a serial to parallel converter in order to receive the information from the processor. This signal will then be weighted as a binary signal and a negative DC offset will be applied to realize both the positive and negative values. The output voltage will then be multiplied by 1.5 so that the highest possible output of the circuit can be acquired. This keeps the output in the linear region of the power of the MOSFET. The final range of the circuit should be -6 to 6 volts and allows the vehicle to operate in the forward and reverse directions.

The eighth bit of the parallel output will be used to supply the negative DC offset for the op amp. When the circuit is at 00000000 and 11111111 the circuit will be able to zero out in both instances. This also allows for a possibility of 128 different voltage outputs, this is more than sufficient enough for the scope of this project. The most significant bit will be used to determine the difference between the positive and then negative. In essence, it will determine whether the vehicle will drive in the forward direction or the backwards direction. When the input is 00000000 this shows that there is no voltage input, when it is 11111111 it shows that there is a positive 6 volts, and when the input is 01111111 it is the maximum negative output of -6 volts.

This binary representation can be manipulated to any voltage between those given ranges and the voltage reading across the motor will change accordingly. It is necessary to have a positive 12 volts and negative 12 volts supplied to the circuit to use as the +/-Vcc that is needed on the MOSFET. This will be done by connecting the two 6 volt batteries in parallel and putting the ground node at the connection point between the two. This 12 volt power supply is also needed to power up the piezoelectric ultrasonic proximity sensor and each of the three voltage regulators.

The DC servo motor control will be slightly more complicated compared to the control circuit for the DC drive motor. Using software, it will be configured to use a pulse width modulation signal with a 50Hz output. The main advantage of using pulse width modulation is that the power loss is very low. To control the motor the active high will be from 1 millisecond to 2 milliseconds. A value of less than 1.5 milliseconds will cause the DC servo motor to spin counter clockwise, turning left. If a value larger than 1.5 milliseconds is recorded, the servo motor will spin clockwise, turning right.

7.2.5 Miscellaneous parts

In order to properly mount each and every necessary component onto the remote controlled car, there are several miscellaneous parts that are also needed but not specifically listed. In order to properly mount the DC drive motor there will need to be a motor mount bought that fits that specific motor. As well as there needing to be multiple resistors and several wires to connect many of the components together. In order for proper biasing to help eliminate noise and create a more clear signal, biasing capacitors will be utilized as well. This is especially important so to create efficient time response to the ultrasonic piezoelectric proximity sensor as well as from the readings received from the headset via the usb receiver.

8. Software Design Content

8.1 Software Overview

The bulk of this project will be the developed software that will take the initial signals sent from the headset and translate them into signals that are useable by the car. This software will be broken into several sections. First, there will be software that will reside in the motherboard. This software will be written using the Emotiv API and its function will to be receive signals from the headset, determine what the signal is, send the signal to the translator and finally send the translated signal to the car.

The other section of software will be used in the custom PCB. This PCB will have the same functionality as an Arduino board, therefore the software will be written using the Arduino syntax. This segment of code will be used to translate the signals that are sent from the motherboard. These two sections of software will be useless without each other because although the Emotiv software will acquire the signals and filter them to the proper handlers, the signals will only be made into meaningful commands in the translator.

This software will be managed using wait times. It will be necessary to make sure there is no "bottle-neck" in this code, meaning that one section is slowing down the rest of the code. Wait times will be used in order to make sure that the correct number of signals are received per second. It will be important to make sure there are not too many signals received or that there are not too few signals received. If too many signals are received, it is possible that the car will be overwhelmed with commands and will behave unpredictably. If too few signals are received, it is possible that a lag will occur, thus making it difficult to achieve real-time execution.

Testing of this software will consist of using both the headset as well as the Emotiv EmoComposer. The reason for this is simple. Before any efforts are made to begin understanding the signals sent by the headset, it will be important to make sure that the developed software is processing the signals correctly. This can be achieved without having to use actual, raw signals by using the EmoComposer.

The EmoComposer is a program distributed by Emotiv that allows developers to mimic the sending and receiving of signals. This program works exactly like the headset, meaning it requires the software to open a connection to it and also

requires it to close the connection when all signals are received. This will be extremely useful for this project because it will allow testing to begin before any actual signals are received. If the code is proven to work with the simulated signals from the EmoComposer, then it will eliminate many possible sources of error when the actual signals are included in the translation process.

8.2 Emotiv Software

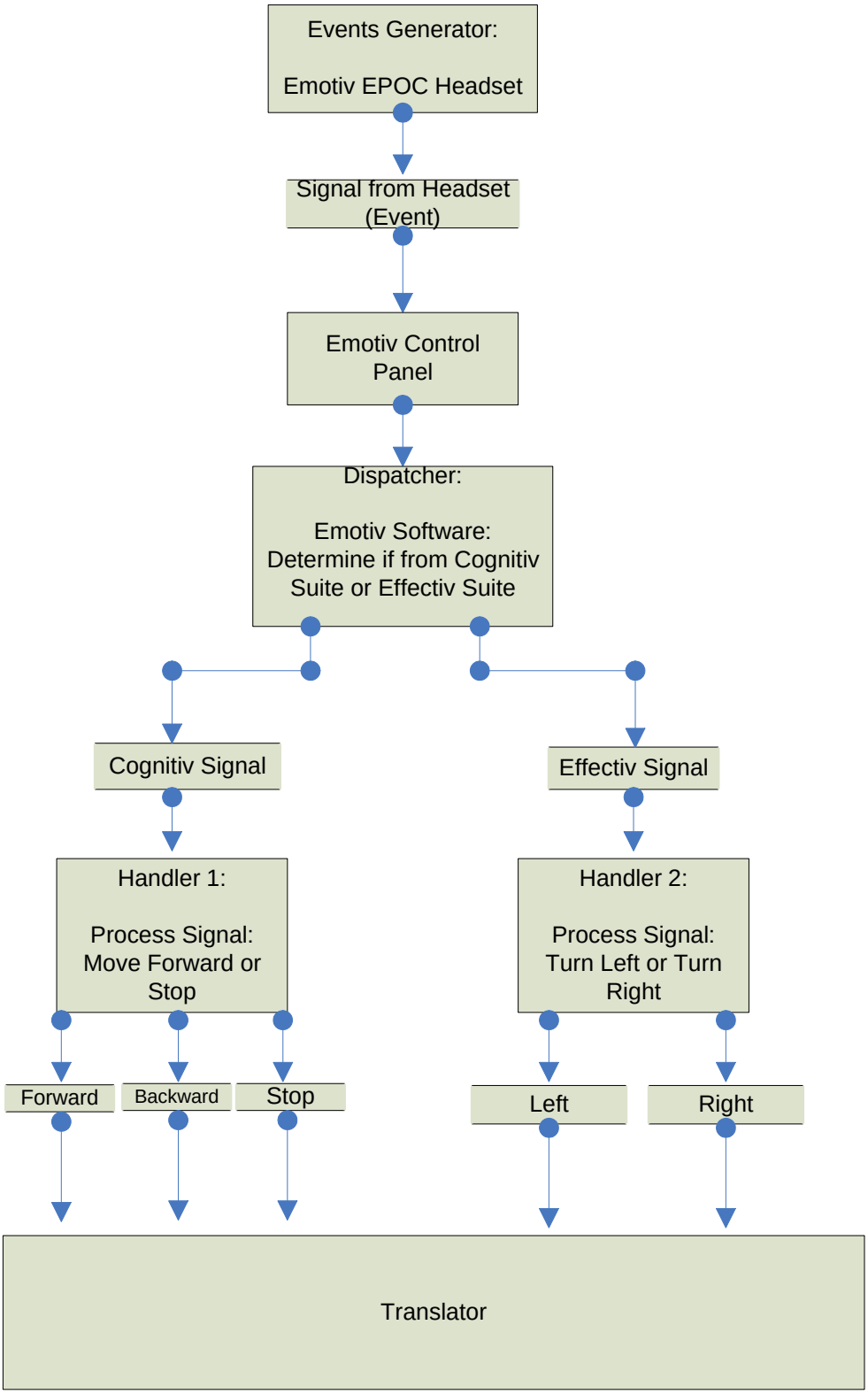
During the process of designing software for the Emotiv EPOC headset, one of the initial steps is to determine what architectural style will be used. During the design of this project, the following styles were considered:

- Client/Server
- Pipes and Filters
- Service-Oriented
- Event-Driven

After much consideration, it was decided that the Emotiv EPOC software would use an Event-Driven Architectural Style. This style was chosen for this project rather than the other mentioned styles because it is based entirely on events or an "identifiable occurrence" (Rouse). This style produces, detects and consumes events, which means each signal sent from the headset will be considered an event production and will be detected as well as consumed by the motherboard and RC car. This is different from the client/server style because this design creates events and these events trigger processes. In the client/server style, the client first makes a request to the server, and then the server responds with a message. This would not be useful for this project because the RC car will not be requesting signals and the headset will not be waiting for requests but instead, the headset will send signals whenever the user decides to send a new command and the car will execute the commands as they are processed and sent. The Pipes and Filters style was not used in this project because this style does not handle events very well. The decision making required to handle each sort of event sent from the headset would not be handled well using this architectural style. Finally, the Event-Driven style was chosen over the Service-Oriented style because the Event-Driven style was able to handle message routing. This was considered important because the events sent by the headset will need to be processed and routed at runtime, meaning there won't be a consistent data flow at all times. Due to this, the capabilities of the Event-Driven style were chosen to handle changes in the flow of the system.

A block diagram showing how the Event-Driven style will be applied to this project is included below in Figure 8.1:

Figure 8.1: Emotiv Software Event-Driven Architecture



The figure above briefly shows the flow pattern that this section of software will follow. The events (meaning, the signals sent to the computer) will be generated by the headset and will be sent to the Emotiv Control Panel. Each of these signals is referred to as an EmoState. Each EmoState will trigger a new event for the software to process. From there, a dispatcher will obtain the signal and determine which handler will be able to interpret and process the signal. The dispatcher will then send the signal to the proper handler. The handler will then process the signal and determine what command the signal contains. This means that the dispatcher will only determine whether the signal was cognitive or a facial expression. It will be the handler's job to determine the exact command being sent by the headset. Once the necessary information is acquired from the signal, it will be sent to the next software phase where the custom PCB will interpret and translate the signals into useful commands.

The first important task that will need to be done in the software will be to establish a connection between the headset and the motherboard. The connection is made with the Emotiv EmoEngine program. This means that in order to gain access to the data sent by the headset to the processor, the software will have to connect to the EmoEngine. This is easily done by calling the EE_EngineConnect() method. A successful connection is confirmed with the following block of code:

Source: Emotiv. Emotiv Software Development Kit User Manual for Release 1.0.0.5. pg 48

```
if (EE_EngineConnect() != EDK_OK)
{
    throw std::exception("Emotiv Engine start up failed.");
}
```

Reprinted with Permission from Emotiv

This block of code calls the EE_EngineConnect() method and checks to make sure that the response received from it is EDK_OK, meaning the connection was successful. The hexadecimal value 0x0000 corresponds to this response, meaning if any other hexadecimal number is received, the code throws an exception and lets the user know that the EmoEngine could not be accessed.

Once a connection is established, the next step will be to begin receiving signals from the headset. This means the code will need to run in a loop in order to get all the signals sent from the user until the connection is closed. During each iteration of the loop, the code will receive a signal from the headset. If the signal represents a valid state, then a new event will be made which will then be used to determine whether the received signal represents a new command. The method used for obtaining the newest event is EE_EngineGetNextEvent(eEvent), where eEvent is the current event. The result of this method call is an integer, which can then be used to determine whether the new state is valid or not. If the

result corresponds to the state of EDK_OK, then the event is valid and can be used. Once again, the EDK_OK response is represented by the hexadecimal value of 0x0000. Any other value will mean that the state is either invalid or there is no new state being received at that particular time.

After the received state is confirmed to be valid, it will then be necessary to verify if the received signal represents a new command or if it is the same as the previous command. Signals received from the headset will be tested with the EE_EmoEngineEventGetType() method. This method will return the type of the most recent signal from the headset. The range of event types is shown below in Appendix 3 of the Emotiv User's Manual and is included below:

Source: Emotiv. Emotiv Software Development Kit User Manual for Release 1.0.0.5. pg 77

EmoEngine events	**Hex Value**	**Description**
EE_UserAdded	0x0010	**New user is registered with the EmoEngine**
EE_UserRemoved	0x0020	**User is removed from the EmoEngine's user list**
EE_EmoStateUpdated	0x0040	**New detection is available**
EE_ProfileEvent	0x0080	**Notification from EmoEngine in response to a request to acquire profile of a user**
EE_CognitivEvent	0x0100	**Event related to Cognitiv detection suite. Use the EE_CognitivGetEventType function to retrieve the Cognitiv-specific event type.**
EE_ExpressivEvent	0x0200	**Event related to the Expressiv detection suite. Use the EE_ExpressivGetEventType function to retrieve the Expressiv-specific event type.**

EE_InternalStateChanged	0x0400	**Not generated for most applications. Used by Emotiv Control Panel to inform UI that a remotely connected application has modified the state of the embedded EmoEngine through the API.**
EE_EmulatorError	**0x0001**	**EmoEngine internal error.**

Table 8.1 : Event types in Emotiv software. (Reprinted with permission from Emotiv)

If the signal is not the same command as the previous one (meaning the user has changed their facial expression or their cognitive command), then the method will return EE_EmoStateUpdated (0x0040) as its result. This will mean that a new command is being called and this new EmoState will be placed in the buffer to be processed by the translator. This is possible due to the format in which the signals are received by the software. An example signal from the code is shown in Figure 8.3:

Example Signal Received From Headset

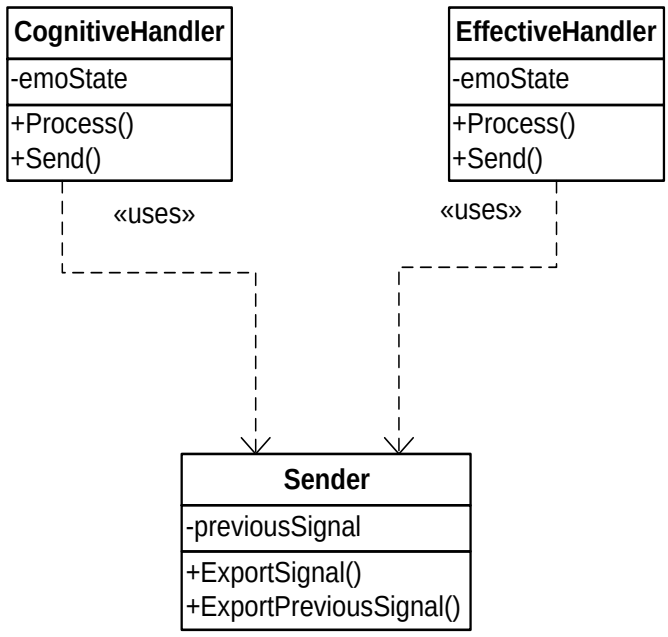
"1.50129,0,2,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,2,0.4"

These numbers represent the following values: Time, UserID, Wireless Signal Status, Blink, Wink Left, Wink Right, Look Left, Look Right, Eyebrow, Furrow, Smile, Clench, Smirk Left, Smirk Right, Laugh, Short Term Excitement, Long Term Excitement, Engagement/Boredom, Cognitiv Action, Cognitiv Power.
In this example, it is seen that this signal was a Cognitiv Action represented with the value "2", which is the "push" action and it had 0.4 Cognitiv Power. Using this sequence of values, the program can quickly and easily determine if this signal is new or not. This is important because this will save time in the processing and executing of the signals if all redundant information is removed from the process as soon as it is received.

The next step to this process will be to send the new EmoState to the corresponding handler. This project will be using Cognitive and Effective signals from the headset. A new EmoState will be acquired from the headset whenever an updated signal is received. The signals from each suite are handled differently and the Cognitive signals will require prior training in order to process the signals correctly. Signals from each suite will be handled in separate classes, CognitiveHandler for cognitive signals and EffectiveHandler for facial expressions. These two classes will have methods that will be able to take the

signals from the suites and extract the necessary information from them in order to send it to the car. The necessity of two different handlers arises from the fact that the two suites will send signals using two different formats. The Effective suite will send its signals using strings and integers. These signals will be easier to interpret and process. The Cognitive suite, however, will be sending signals in bits and pieces. There are fourteen sensors on the headset, and it will be necessary to receive and analyze data from each of the these signals. Due to this, the handling of effective (facial expression) signals and cognitive signals will be completely different. The end result, however, will always be a useable signal that will be sent to the car for execution. The class diagram below shows both handler classes and how they interact with each other as well as with the Sender in Figure 8.4:

Figure 8.2: Class Diagram: Handler Interactions



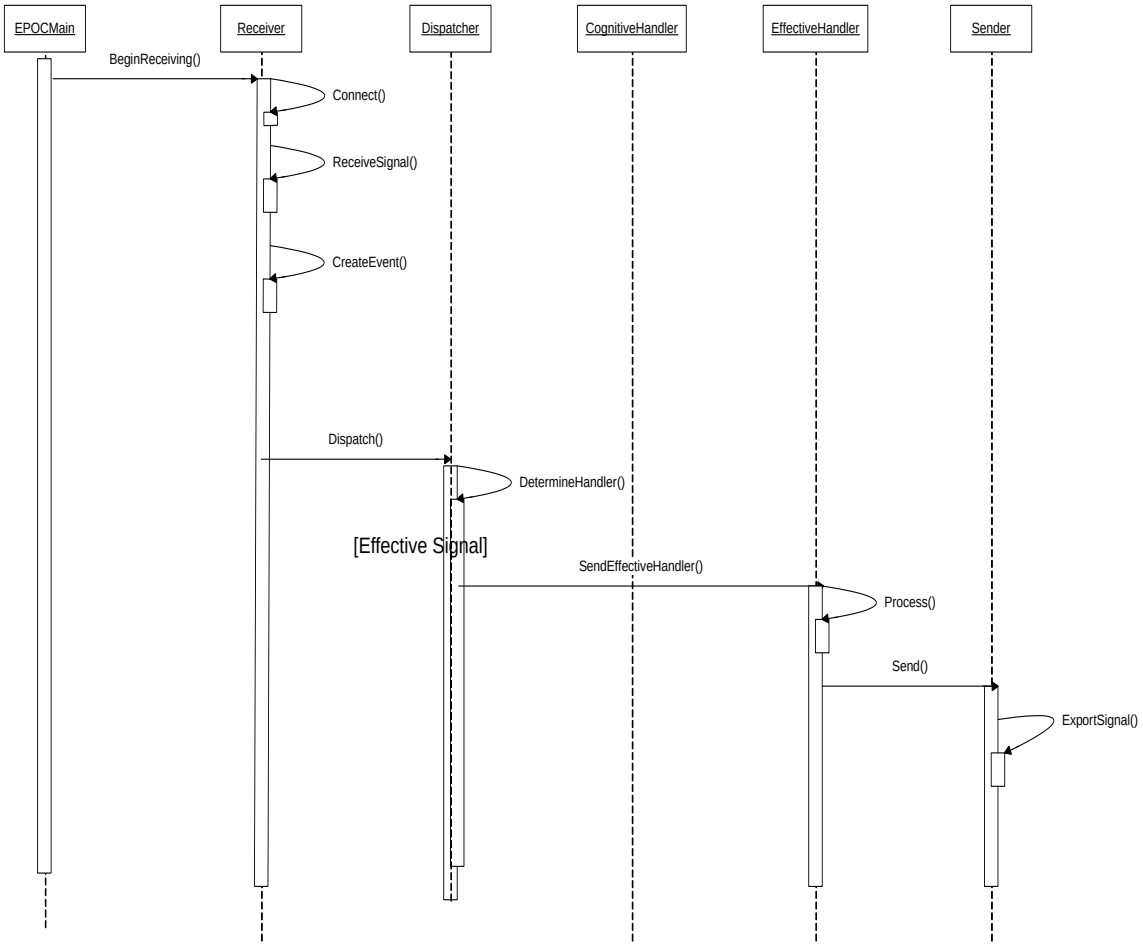
The methods that will be used in each class are explained below in Table 1:

Table 8.2: Classes and Methods of Emotiv Software

Class	Method	Explanation
EPOCMain	BeginReceiving()	Makes an instance of the Receiver class and begins process of communicating with headset
Receiver	Connect()	Opens a connection between the mounted processor and car
	ReceiveSignal()	Gets signal sent from the headset
	CreateEvent()	Uses signal to make an EmoState
	Dispatch()	Makes an instance of the Dispatcher class and handles the signal
	Send()	Makes an instance of the Sender class and sends repeated signal straight to the car
Dispatcher	DetermineHandler()	Receives an EmoState as a parameter and determines which handler is necessary
	SendCognitiveHandler()	Makes an instance of the CognitiveHandler class and handles signal
	SendEffectiveHandler()	Makes an instance of the EffectiveHandler class and handles signal
CognitiveHandler	Process()	Takes EmoState and extracts all necessary information
	Send()	Makes instance of the Sender class and begins process of sending final signal
EffectiveHandler	Process()	Takes EmoState and extracts all necessary information
	Send()	Makes instance of the Sender class and begins process of sending signal to car
Sender	ExportSignal()	Sends extracted information
	ExportPreviousSignal()	Re-sends the previous information

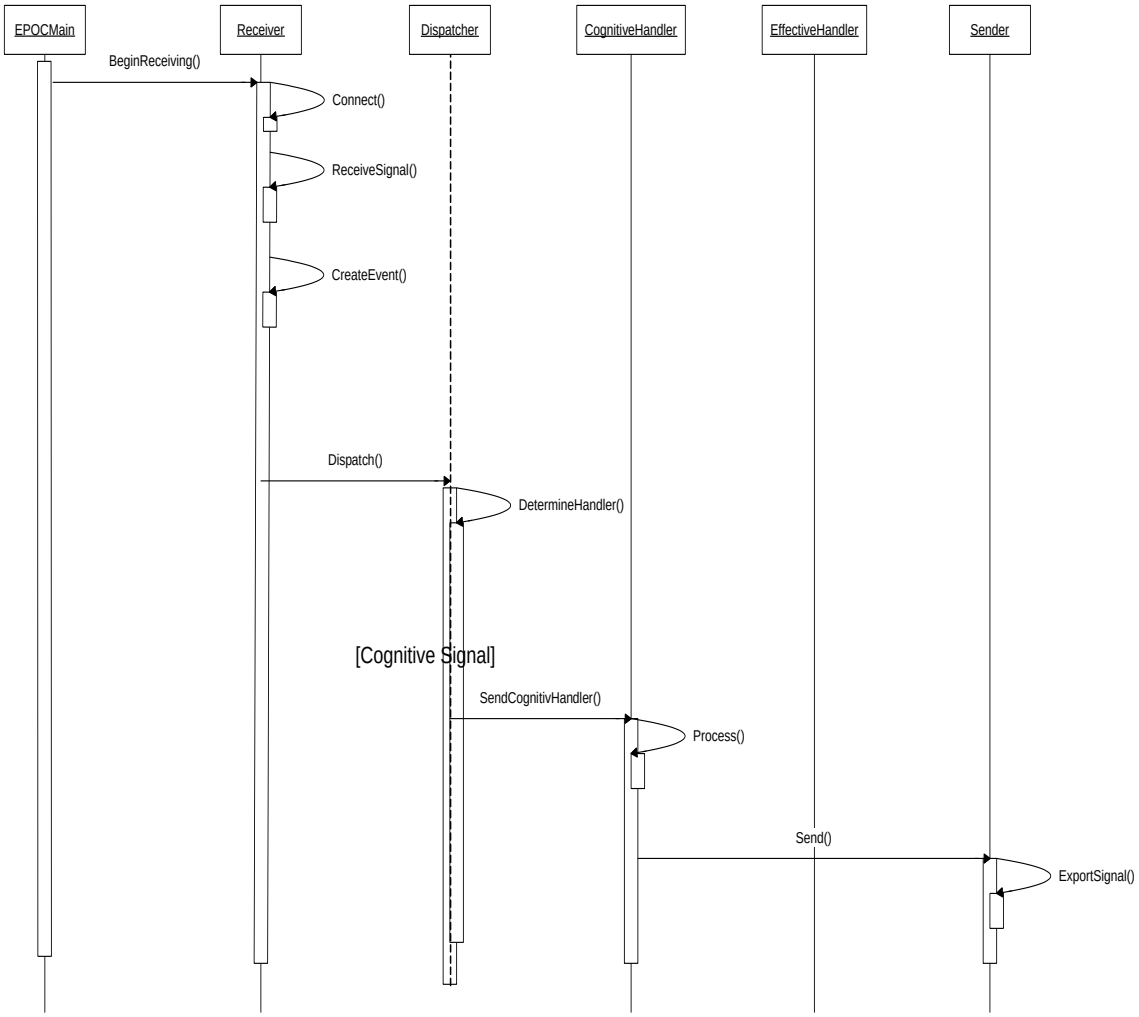
Overall, this software will have 3 separate sequences for successful signals. The first possible sequence will be successfully receiving a new facial expression command. The sequence for this event is shown below:

Figure 8.3: Effective Signal Sequence



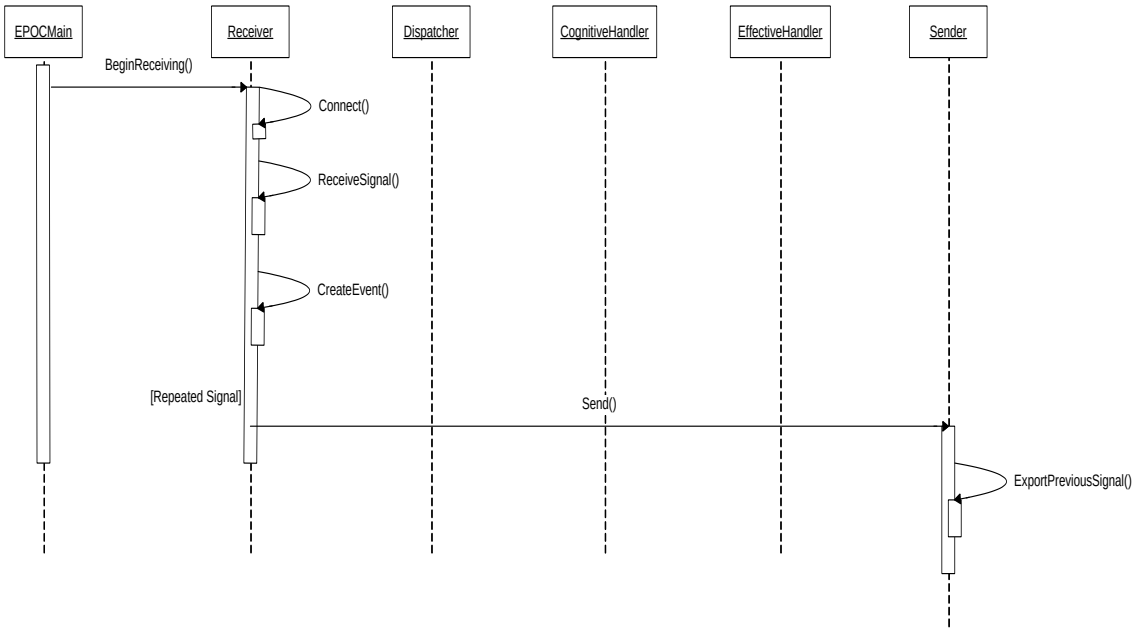
In this sequence, an instance of the EffectiveHandler class will be made and this will process the signal in order to tell the car to either turn left or turn right, depending on the command sent by the user. The second possible sequence will be successfully receiving a new cognitive signal. This sequence is shown below:

Figure 8.4: Cognitive Signal Sequence



This sequence will create an instance of the CognitiveHandler class which will put together all the raw EEG readings and tell the car to either move forward, backward or stop, depending on what command the user sent. The final sequence that will be handled by this code will be successfully receiving a repeated signal. This will occur, for example, when the car is moving forward and the user wants the car to continue to move forward. This will be equivalent to holding down the accelerate button on the remote control of the car. This sequence is shown below:

Figure 8.5: Repeated Signal Received



In this sequence, no handlers will be used. Instead, the Sender class will be used. After each successful signal, the Sender class will keep track of the signal that it sent to the translator. If the ExportPreviousSignal method is used, then it will send the signal that was most recently sent to the translator. This will save processing time and will allow for more accurate maneuvers by the car.

Any effective signals that are used in this project will be used to turn the car left or right. The facial expressions that will be used are a right or left wink. In the Emotiv API, facial expressions using winking can be handled by using "Eye related actions" (Emotiv, 50). The functions ES_ExpressivIsLeftWink and ES_ExpressiveIsRightWink will be used at first in order to verify if the user is winking with their left or right eye. This will determine which eye the user is winking by returning either true or false. When the correct eye is determined, the Expressiv action type will be set to either wink left or wink right. This action type will then be made into a String, which will be passed to the Sender class in order to send it to the translator. A table showing the strings assigned to each command is shown below:

Table 8.3: Strings Assigned to Facial Expression Commands

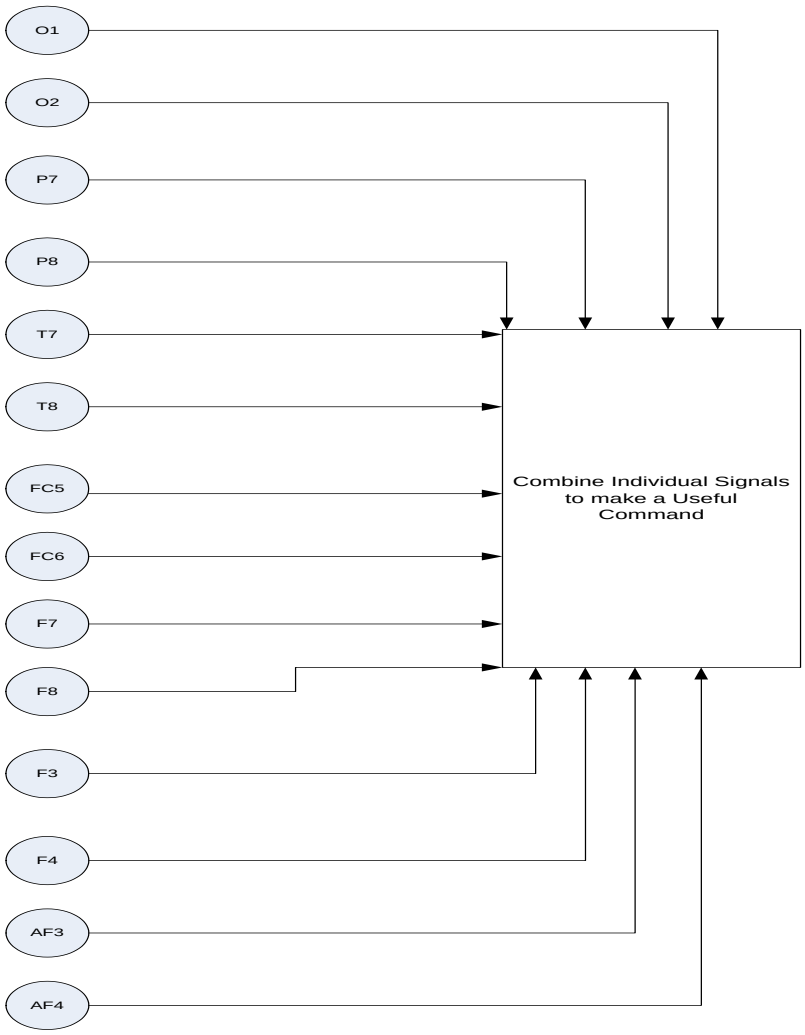
Facial Expression	Assigned String
Wink Left	"WL"
Wink Right	"WR"

The Sender will confirm that the string passed is a valid string. If the string sent is invalid, or if no string is passed, the command will be ignored and the Sender will wait for the next signal to be sent.

The Emotiv API also allows for the retrieval of the intensity of the command. This is used to measure the movements made by the user. An example of the use of this would be to measure how high the user's eyebrow is raised. This aspect will not be used for the Expressiv actions in this software. A simple wink will always trigger the same turning action for the car.

The cognitive signals in this project will be used to move the car forward, backward and to stop the car. These signals will be acquired by using raw EEG data sent from the headset. This raw data will be taken from each of the 14 sensors by using the EE_GetData function. The name of each sensor will be used as a parameter in the EE_GetData function in order to know which sensor is being used to retrieve information. For each command, the most current data from each sensor will be retrieved. This data will then be used to determine which command is being sent by the user. The figure below shows the process for receiving and interpreting the raw EEG data:

Figure 8.6: Receiving Raw EEG Data



In order to map these signals to any useful commands, it will first be necessary to learn how to read and interpret the EEG readings sent to the Emotiv Control Panel by the headset. This will be done by using the data displays on the control panel as well as the testbench and learning which sensors on the headset are triggered when a move forward, backward or stop command is given. Once these patterns are learned, it will be possible to write conditions which will be able to read all the raw signals from each sensor into translate them into a single command. Once these commands are made, they will also be made into strings which will be passed to the Sender as well as the translator. These strings are shown below:

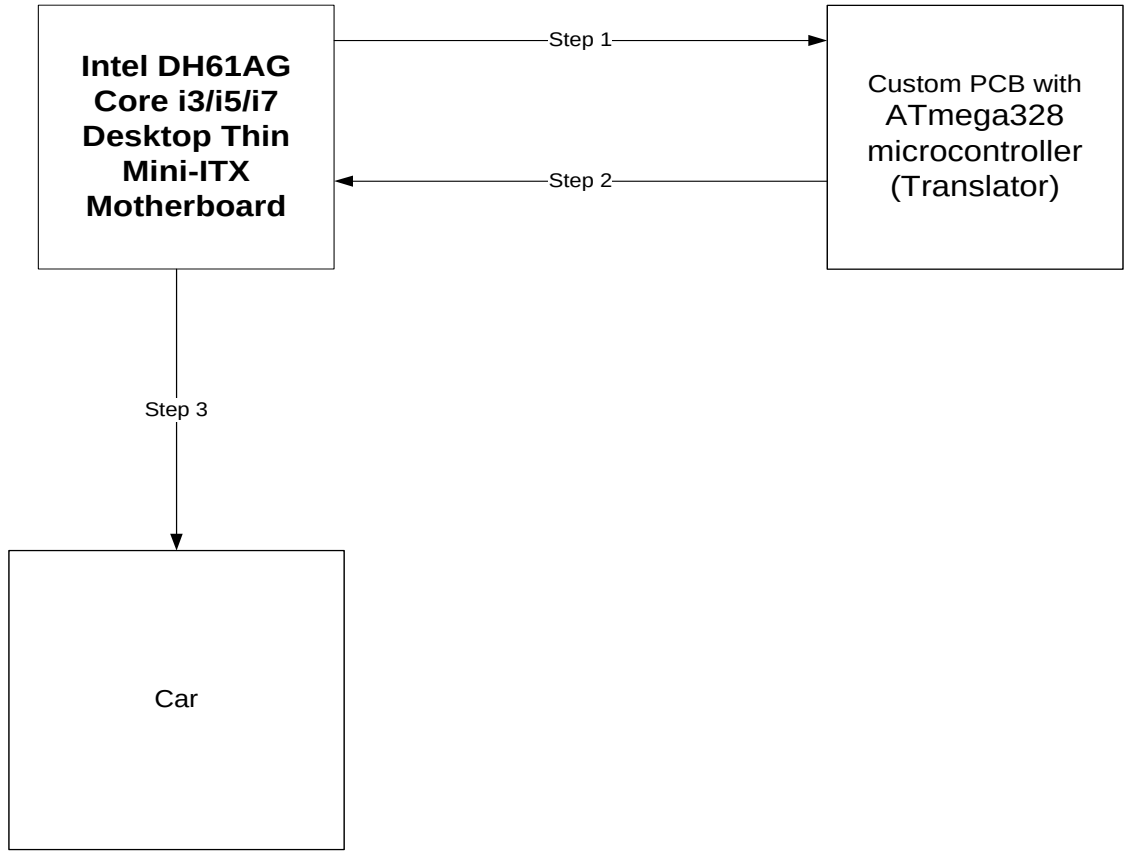
Table 8.4: String Assigned to each Cognitive Command

Cognitive Command	Assigned String
Move Forward	"MF"
Move Backward	"MB"
Stop	"SP"

Once the signals have been made into EmoStates and these EmoStates have been handled, the extracted information will then be sent to the translator. The translator will be a custom PCB that will have the ATmega328 microcontroller embedded on it, thus giving it the same functionality as an Arduino board. The data will be sent to the arduino via a socket connection which will allow for data transfer between the two devices. The socket connection will also be coded in C++. The physical connection between the motherboard and the PCB will be made with a USB cable. This was chosen for this project because it will ensure a more reliable connection and therefore will provide a greater probability that the data sent from the motherboard to the PCB will be received.

The data transfer between the motherboard and the PCB will be initiated by the motherboard. As soon as the motherboard has new extracted data from the EmoStates, it will send the data to the PCB. The PCB will then translate the information into an 8-bit stream which will be sent back to the motherboard once it is created. This 8-bit stream will then be sent to the car via a wireless connection. This data flow sequence is shown below:

Figure 8.7: Data Flow from Motherboard to Car



In this diagram, it is shown that the motherboard will first send the extracted data to the translator. The translator will then send back an 8-bit stream to the motherboard and finally the motherboard will then transmit that 8-bit stream to the car.

When this software is completed, it will be packaged into a project solution using Visual Studio. This solution will contain all the source code as well as the necessary header files and libraries in order to run the code successfully.

8.3 Custom PCB (Arduino) Software

Programming the Arduino is done with sketches written in C into the text input area provided by Arduino software environment that gives the Arduino the instructions to follow by compiling and uploading the sketches to the Arduino board. The purpose of using the Arduino PCB is to program its ATmega328 microcontroller with a software translation program- thus functioning as the translator of the signals received as needed for this project. A picture of an Arduino is below.

It translates the signals received into signals that the circuits on car can use enabling its control. Input is to be received from the motherboard when a new command or events such as Cognitiv thoughts or Facial expressions is created by the functions in the EMOTIV API software such as the information contained in the EmoState. EmoStates data is then extracted by methods and contains the string of the processed data which is then sent to the Translator by the Sender class. Procedures, responses and actions vary depending on the information being processed based off of the type of the demand.

Allowing the microcontroller and the motherboard to send and receive information from each other by opening socket connections the software on the Arduino PCB ATmega328 microcontroller receives the extracted string information from the motherboard the software. Then the software translates this string so into a new eight bit binary stream which is sent back to the motherboard. Next, the motherboard sends this eight bit binary stream to the car for the desired motion action response of the event that triggered it via serial to parallel converter.

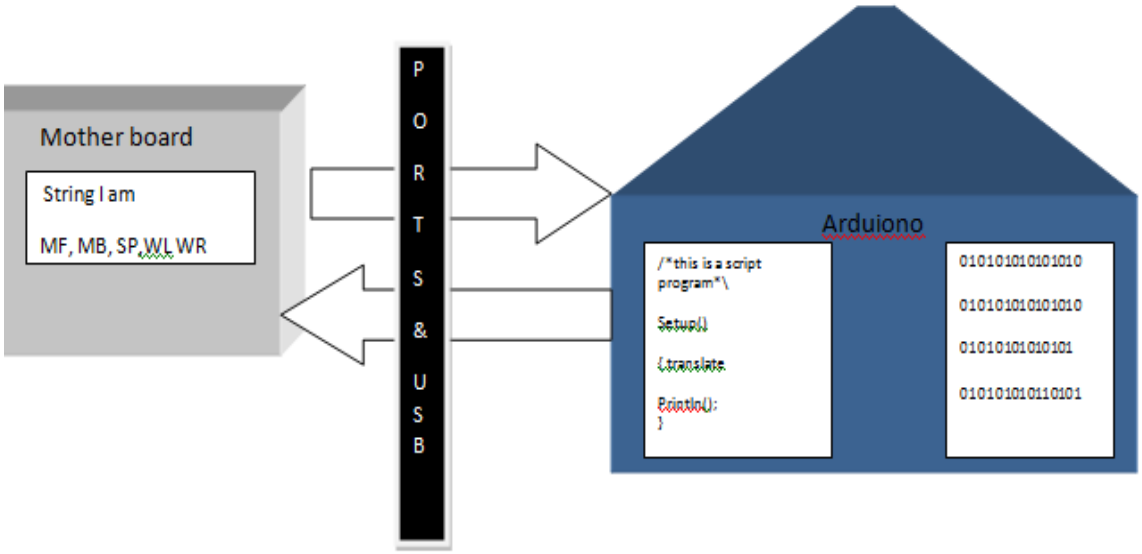


Figure 8.8. Illustrates the connection between the motherboard and the Arduino PCB

Figure 8.9 Shows a view of the overall connections at the different stages shows the communication between the motherboard and the car.

The question is how are the information interpreted and if so what data is made available that can be of use to solve this problem to create an effective translation scheme? Since the input of the microcontroller is in the format of a string, this string may serve as a convenient data which may be used for the algorithm to be implemented to achieve this task. The data provided on the string contains all the content that is needed to implore a strategic algorithm. What if each string being read can be mapped and assigned to a unique binary number? If so how many unique numbers is needed, or is this number equal to the total number of commands that can be read and if so how would we know this in a timely manner before programming? Most of all is this amount truly needed? The answer to these questions comes from the objective of this project. Since it was

decided that only the Cognitiv and the Expressiv suites only were to be used and that in the project the only desired actions is to move the car forward, backward, left, right and to stop the car which are actually already mapped with each of their respective event detection groups and assigned strings from the control panel of the EMOTIV API software with the desired action to control the car with a corresponding string as noted earlier in document.

For instance, for the cognitive detection group commands containing move forward, move backward and stop responses are assigned the strings MF, MB and SP respectively. Just as for the Facial Expressive group commands contains Wink Left (WL) and Wink Right. Each string is assigned a unique control as explicitly hinted out by each commands abbreviation and that each event was assigned a specific control. For example, the MF triggered event expects a motion action to moves the car forward, the MB event moves the car backward, SP stops the car, WL makes a left turn and the WR performs a left turn of the car. Each event type, along with its assigned string and the desired effect, corresponding response to each of the event on the car, and their description are labeled on the tables below as well throughout the document.

Detection Group	Events	Command	Assigned String	Description
Cognitiv: thought	Move Forward	Think forward or cognitive push	MF	Speeds up and Accelerates the RC car
	Move backward	Think to move backward/ back Or cognitive pull	MB	Decelerates the RC car , reverses its current direction
	Stop		SP	Stops the car
Expressiv: Facial express	Wink Left	Turn left	WL	The car makes a left turn
	Wink Right	Turn right	WF	Moves the RC car to the right

Table 8.5 list of events and corresponding commands

Now it is determined the assigned string values for each command is assigned and sent to the Arduino PCB ATmega328 microcontroller to have access to them an algorithm can be implemented to translate this string into an eight bit binary to be recognized by the car in order to perform the control analogous to it's string. This is done by again assigning a unique binary to each command available. The decided values of each command are shown in this updated table below revealing each commands assignment and detail.

Each string is sent to the translator program bit by bit via serial USB of the Arduino PCB. For every string a binary code is assigned by comparing with them to their equivalent American Standard Code for Information Interchange (ASCII). A unique binary value is then assigned each code. Once each has been converted, the bit is sign extended to ensure there are all of the same lengths of eight bit binary. Once translation program is done the information new eight bit binary signal will be sent back to the motherboard where the serial to parallel conversion to conform to the compatibility of the car.

Arduino contains procedures and libraries that will be very useful to implementing this program.

```
void setup()                    // run once, when the sketch starts
{
  pinMode(ledPin, OUTPUT);      // sets the digital pin as output
}
```

Figure 8.10 Setup Command

The above figure shows a procedure called setup( ). Setup ( ) is similar to the main procedure in a C program. It doesn't take in any input and returns void. In this procedure variables are initialized and libraries begin to be used in this function. This procedure runs when a sketch starts.

```
void loop()                     // run over and over again
{
  digitalWrite(ledPin, HIGH);   // sets the LED on
  delay(1000);                  // waits for a second
  digitalWrite(ledPin, LOW);    // sets the LED off
  delay(1000);                  // waits for a second
}
```

Figure 8.11 Arduino code with adaptive response

The loop ( ) function iterates the statements within them repeatedly allowing control of the Arduino PCB board by allowing the program to change and respond as it iterates. Both the setup and loop functions are structures to the language for the Arduino programming language.

Arduino has control structures that may be used such as if, if...else, for, while , switch case, and return for conditional operations, control overflow, repeat code or loop conditionally and etc. Arithmetic are performed with = (assignment operator) storing the value to the right of the equal sign in the variable to the left of the equal sign, + / - for addition and subtraction, * for multiplication, / for division and % for modulo. These are followed by comparison operations with == for equal to,! = not equal to and etc similar to C. The data types are void, Boolean, char, byte, int, word, string, array and etc.

Functions such as Bits and Bytes and Communication will be used in the translation program to read and write bits. Serial communication library communicates between the Arduino board d via serial ports on digital pins 0 (RX) ,1 (TX) and the motherboard through USB. In particular the Arduino environment contains many libraries one of which the Serial library contains a set of procedures as shown in the figure below.

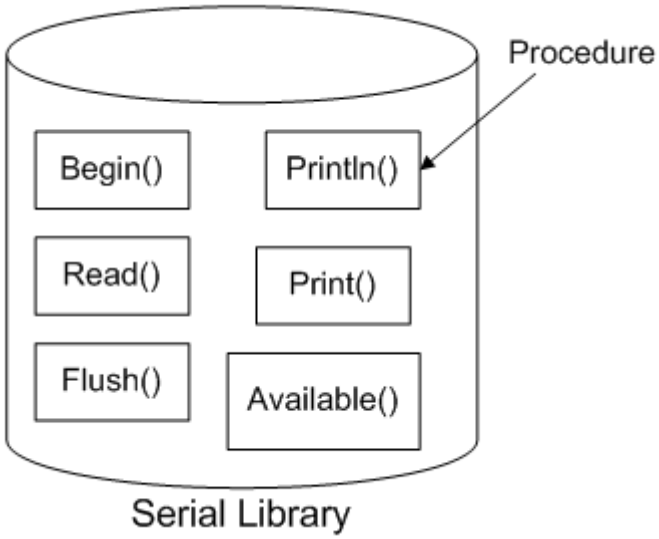


Figure 8.12 Serial library overview

For example this library procedural statement call is a saying that the procedure begin is in the serial library. The input to this procedure is the baud rate which is how fast the connection can read and write the bits on a wire.

```
Serial.begin(9600);          // set up Serial library at 9600 bps
```

Figure 8.13 Serial begin function

Information is being communicated through serial data transfer by setting pins to either high or low, this is shown in the figure below how bits 0 or 1 being transferred one bit at a time due to the USB serial connection between a computer system and a particular model of an Arduino.

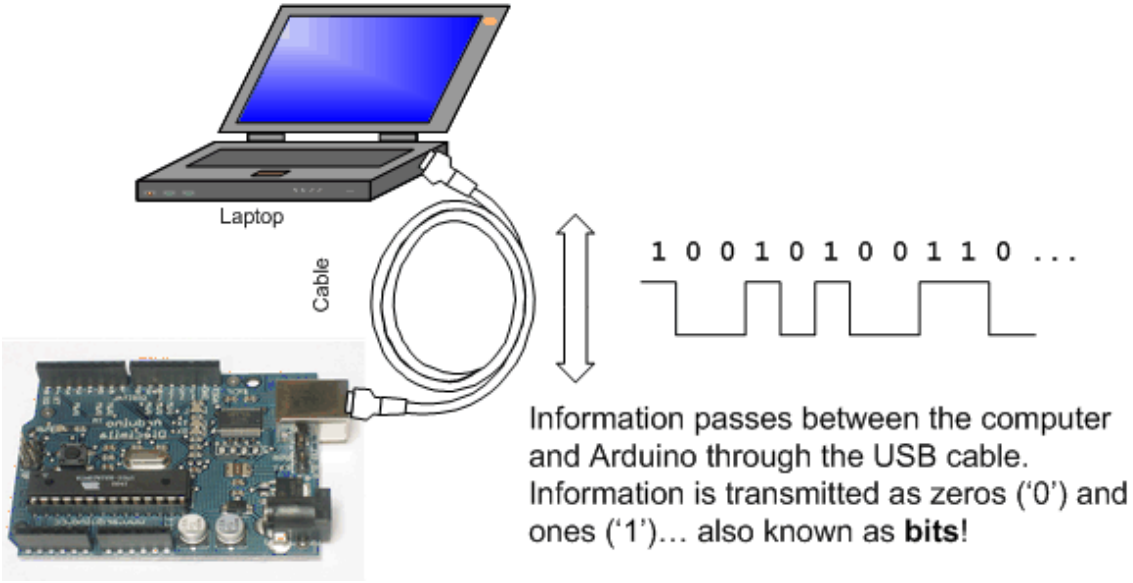

Laptop
Cable
1 0 0 1 0 1 0 0 1 1 0 . . .
Information passes between the computer and Arduino through the USB cable. Information is transmitted as zeros ('0') and ones ('1')… also known as **bits**!

Figure 8.14 Information pathway from DH61AG to Arduino.

When the software is compiled it is translated into binary data. Each bit are sent one at a time through a USB cable connection to the ATmega328 microcontroller of the Arduino PCB during uploading. The RX LED emits when the Arduino receives data and the TX LED lights up once it is transferring data. The data and output can be seen on the Arduino environment serial monitor. The Arduino language has an abundance of functions and libraries. Listed was only a handful of the many options of functions that can be used for the translation program.

How will this program be stored and written in the microcontroller? This is through the unique architectural design of the microcontroller. The ATmega328 microcontroller embedded onto the Arduino PCB is a high performance Atmel 8-bit AVR Reduced Instruction Set Computer (RISC) . This microcontroller is pictured below.

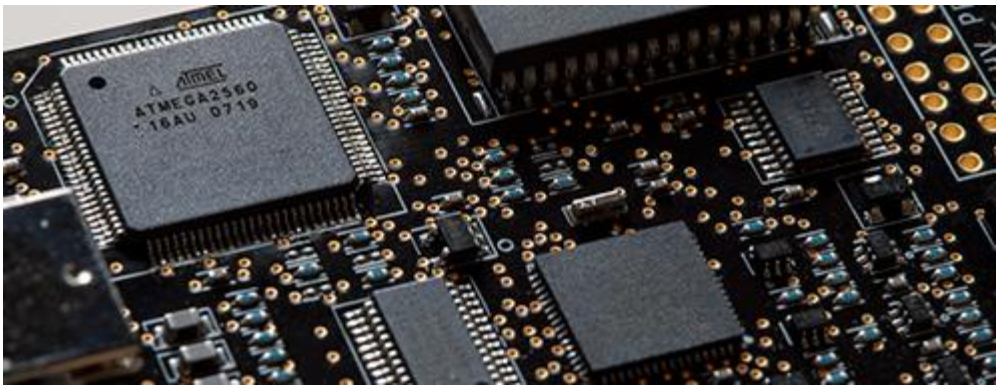


Figure 8.15 Microcontroller

The microcontroller combines flash memory with read-while write capabilities , 1 KB EEPROM, 23 I/O lines, 32 general purpose registers , serial programmable Universal Synchronous Asynchronous Receiver Transmitter (USART) , a byte-oriented 2-wire serial interface, SPI serial port device operating between 1.8-5.5 volts which corresponds to the demands of the motherboard, circuits within the car and the rest of the features needed for our project. Each of these features is important to allow communication between the motherboard and the Arduino PCB and the motherboard and the car. These features also help with the storing of the software so that it may be accessed when needed through wired connections and to process this information and all in real time and quickly with as minimal delay as possible. Instructions are executed in a single clock cycle so to balance power and processing.

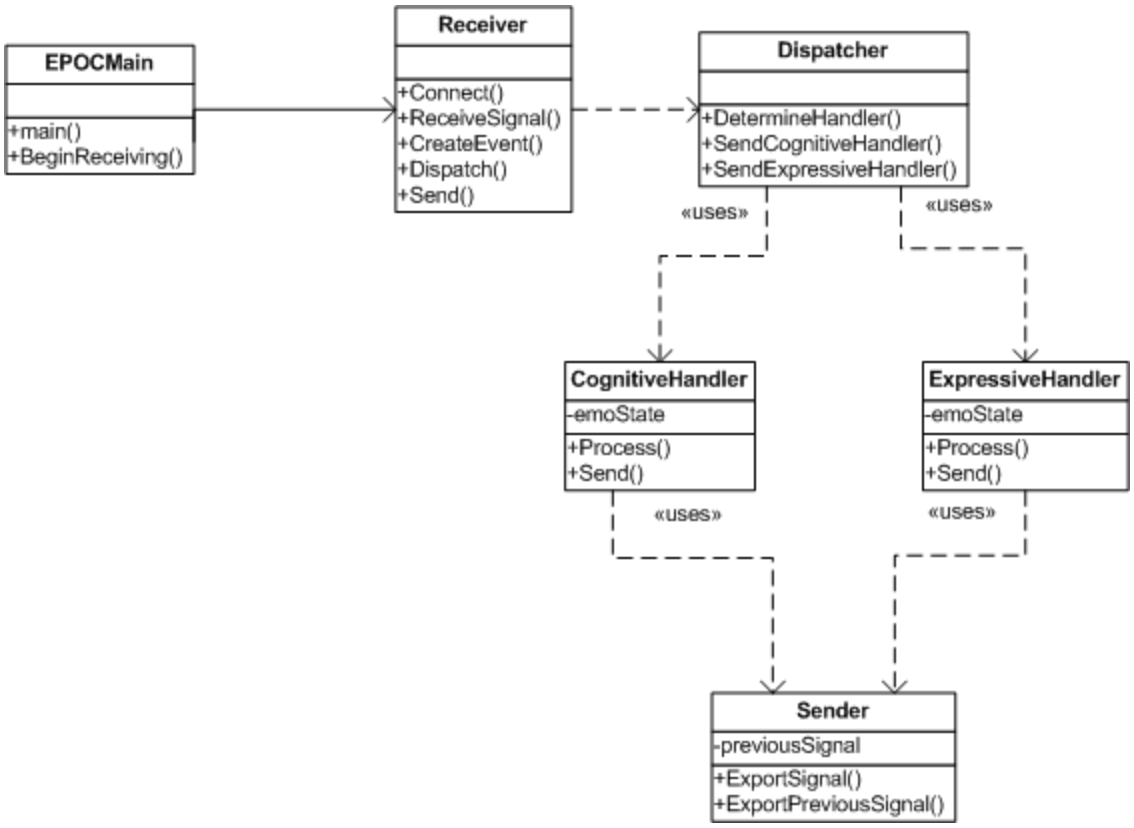
9 Design Summary of Software

9.1 Emotiv Software

The software developed using the Emotiv EPOC SDK is a vital part of this system. The functionality of this software will result in the retrieval of signals from the headset as well as interpretation and processing of these signals using the GUI for the headset. It was decided that this software will be written in C++. This language was chosen due to its object-oriented design which will make it easier to organize the code. Also, much of the software included with the Emotiv package is written in C++, therefore developing the code for this project in C++ will facilitate in merging the code into one project. It was also decided that Visual Studio would be the selected IDE for this project. Visual Studio provides very easy-to-use project organization as well as much C++ development support.

One of the main advantages of using C++ as the programming language for this project is the fact that it is object-oriented. This will allow the code to be organized into classes and reusable code. The class diagram representing all the classes as well as their connections is shown below in Figure 9.1:

Figure 9.1: Class Diagram

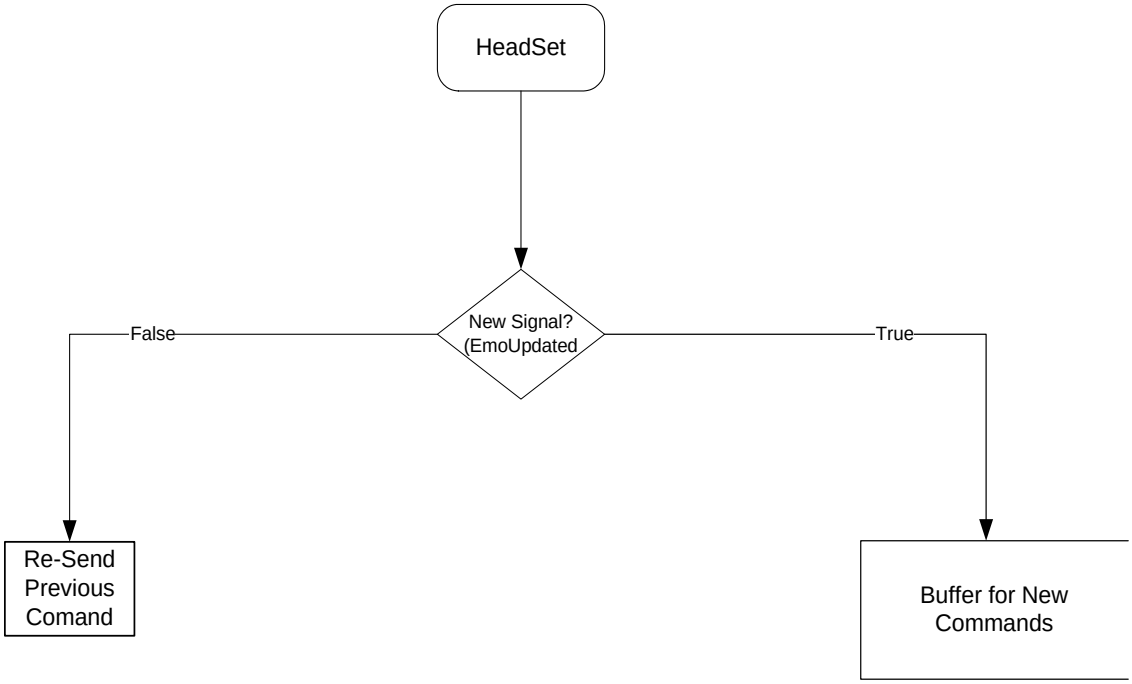


The Emotiv Research Edition SDK comes with several GUIs as well as its own API that proved to be very helpful for this portion of software. Along with all these features, Emotiv also included a user manual with example code that allowed the group to become more familiar with the API. The first task to be completed will be to write code that will establish a connection between the motherboard and the headset. This will be important because the headset is already programmed to send signals that are processed and displayed on the GUI. A connection between the processor and the headset will allow for extraction of this data which means it will be possible to manipulate it and use it however necessary.

Once a connection is confirmed, the next step will be to begin receiving signals from the headset. This will need to be a continuous process to make sure all signals are received until the user decides to disconnect the headset from the computer. In order to do this, the block of code that will receive and handle all signals from the headset will be placed in a while loop that will continue to run until the code breaks out of it.

During each iteration of the loop, the code will receive a signal from the headset. If the signal represents a valid state, then a new event will be made which will then be used to determine whether the received signal represents a new command. According to the Emotiv User's Manual, "For near real-time responsiveness, most applications should poll for new EmoStates at least 10-15 times per second." (User's Manual). This means that it will be important to make sure the loop runs enough times to record real-time readings from the headset. This, however, brings up another problem. With so many loops and signals, there is a possibility that the program will be overwhelmed with data. In order to avoid this, each signal will first be tested in order to check if the command is new or if it is the same command as the current, running command. The code will follow the diagram in Figure 9.2:

Figure 9.2: Flow Chart for Determination of New Signal



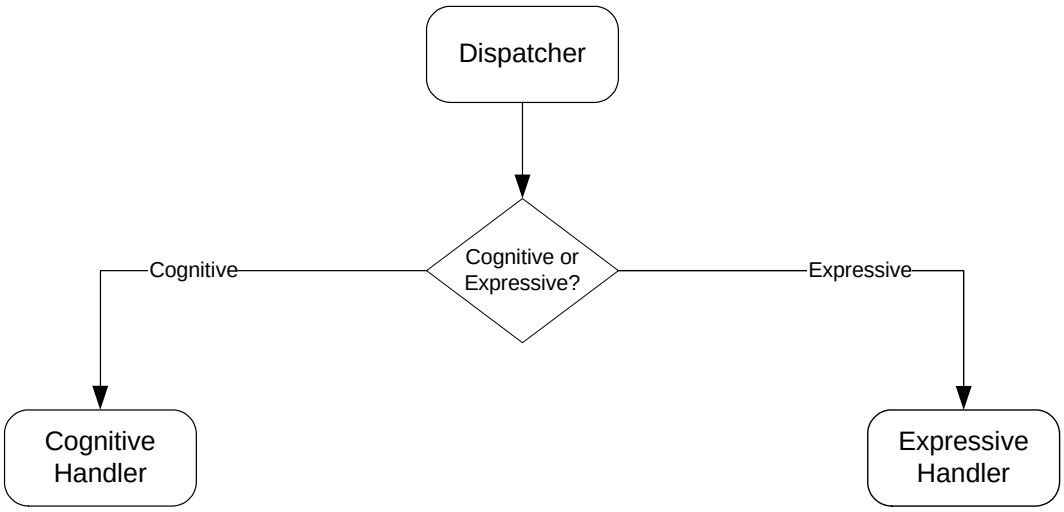
This diagram shows that any signals that are not new will be ignored and the code will simply wait for the headset to send a new signal. This does not mean, however, that nothing will be done. If the same signal is received, then the same command will be sent to the car, which will be equivalent to holding down a button on the remote control of the car. The importance of this step is that it will reduce the amount of time needed to process signals because the repeated command will not be sent through the translation process. Instead, it will notify the car that the same command as the previous one should be executed. In order to save time, the signals are not processed during this stage. They are only checked to make sure that the raw data does not match the data received from the previous signal.

As signals are confirmed to be new signals, they will also be checked for compatibility. This means, for example, if the current command is moving the car forward and the new command is to turn left, then the new command will be executed along with the current command. However, if the current command is moving forward and the new command stops the car, then the current command will be stopped and the new command will be applied until the user changes the command again.

For this project, signals will be taken from both the Cognitiv Suite and the Expressiv Suite. The Cognitiv Suite receives the EEG waves sent by the headset

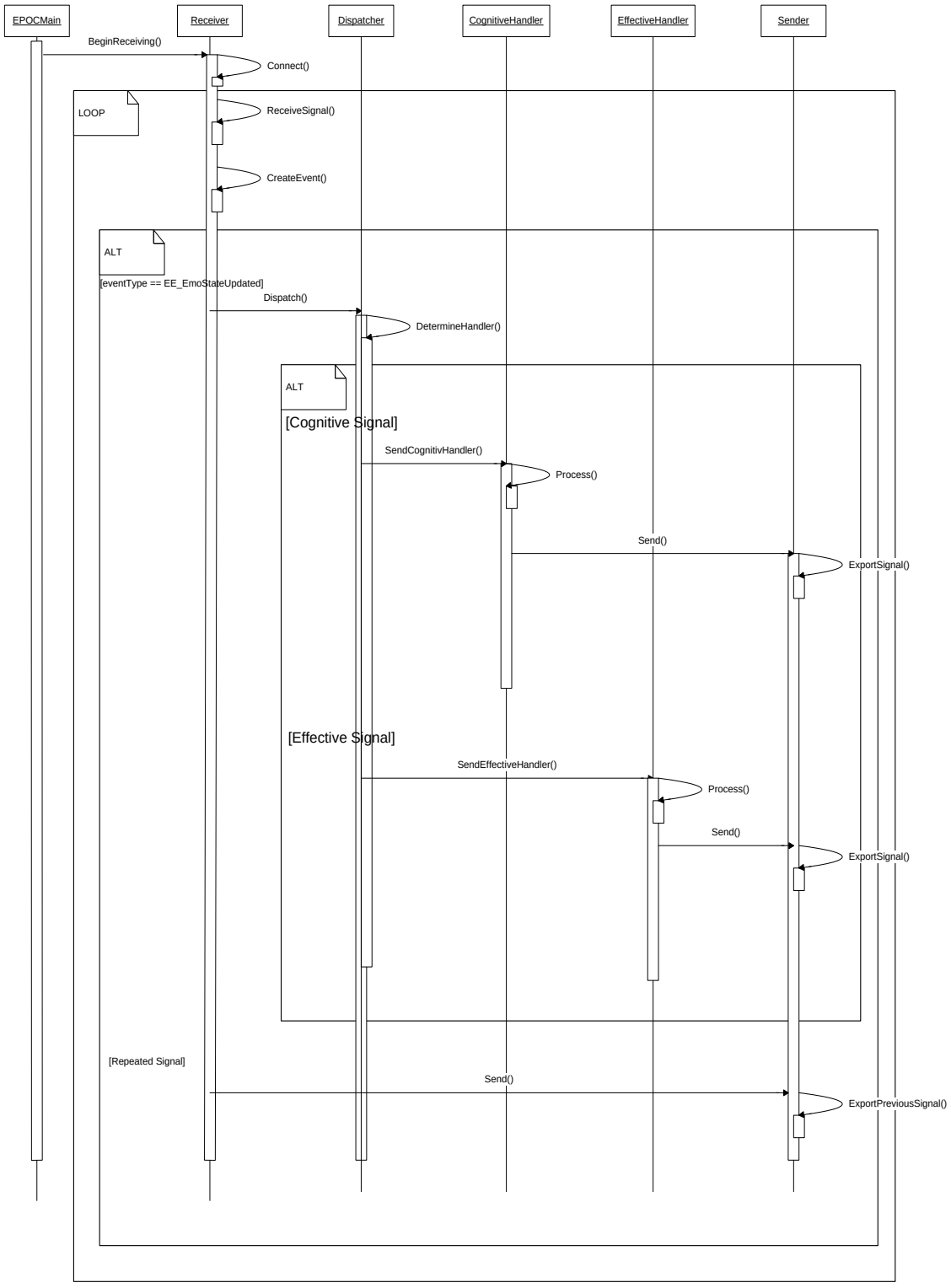
and applies them to commands such as "pull" and "rotate" which can lead to physical movements. The Expressiv Suite uses facial expressions to send commands. Both of these suites together will be used to control the RC car. The signals will be filtered once they are received by the processor and will be sent to the corresponding handler. The handlers will know how to process the signal and will extract the necessary information from it. Figure 9.3 below shows the data flow for this segment:

Figure 9.3: Data Flow for Signal Filtering to Correct Handler



A sender class will be the last class in this code, which will be used to send all the extracted information from the current EmoState to be translated into a useable signal for the car. The overall sequence for this software is shown below and a breakdown of the different possible sequences is included in the software design content:

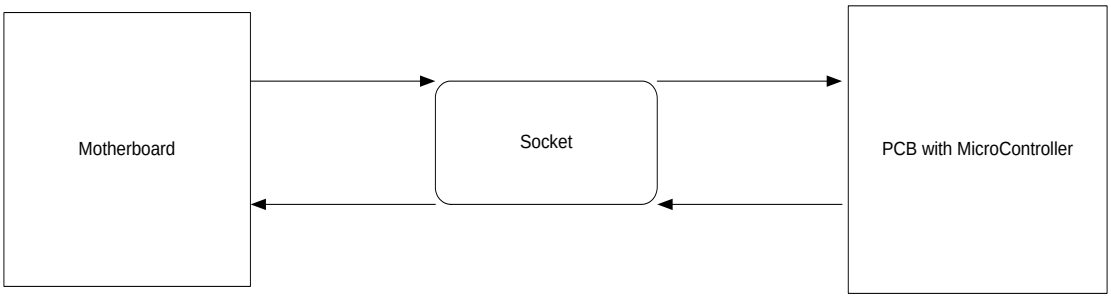
Figure 9.4: Sequence Diagram of Developed Emotiv Software



Once all the necessary information is extracted from the EmoStates, it will be necessary to send the information to the microcontroller on the PCB connected to the motherboard. This PCB will function as the translator for our signals. In this phase of the software, the information will be processed into signals that can be sent to the car which will give it commands.

In order to send signals between the motherboard and the microcontroller, it will be necessary to open a socket connection which will allow the devices to send information to each other and receive information from each other as well. A socket connection was chosen for this portion of the software because it is the best connection when directly connecting two different devices. A diagram showing the functionality of the socket is included below:

Figure 9.5: Socket Connection



Once the translation process is complete, the new data, which will be an 8-bit stream will be sent back to the motherboard and the motherboard will then send the 8-bit stream to the car.

9.2 Custom PCB (Arduino) Software

Arduino is an open source microcontroller built onto a printed circuit board (PCB) to provide the necessary electronic connections. The Arduino functions as an interactive device by receiving input from sensors to manipulate devices that are connected to it. With a microcontroller embedded onto the PCB, input and output port signals are provided that enables digital information to be communicated between the Arduino and a physical real world peripheral. The Serial port on the controller, allowing processed information to be passed in a bidirectional manner sends one bit at a time in the order that they are initiated in a stream of buffer. Ports can be selected so that they are connected to a desired corresponding external device such as computers, monitors and etc. through Universal Serial Buffer (USB). I/O operations can be used for read and write or to turn off and on materials and devices by having the pins being set to high or low. Connections are shown in the figure below.

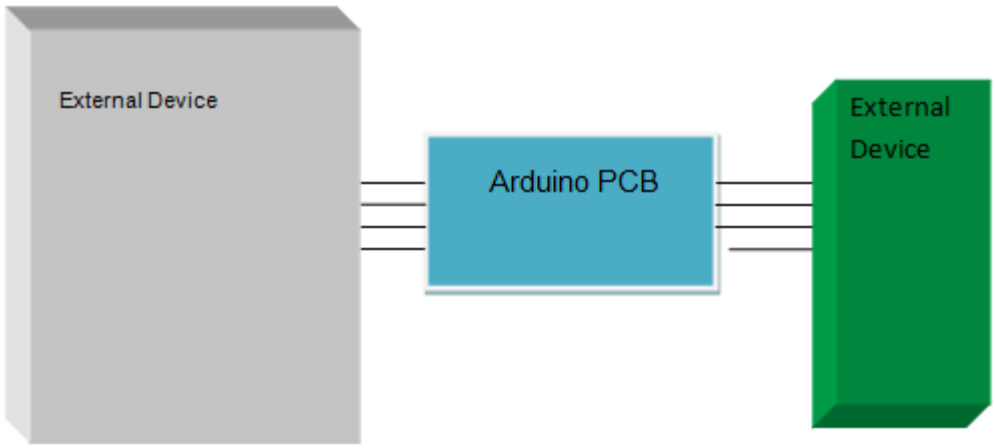


Figure 9.6 Input/Output paths through the Arduino

The microcontroller is preprogrammed with Arduino software environment and uses sketches which are instructions to tell what the Arduino to do. Once a sketch program is completed it is verified and compiled which debug the code and translate it into an application that is compatible with the Arduino hardware in order to upload the written software onto the Arduino board. The board must be reset either done manually (pressing a black button on the board) or automatically depending on the type of Arduino used in order to upload a new sketch onto the microcontroller. Arduino is very popular because of how it is open source and ease of use of hardware and software. There are many different types of Arduino boards and there are also many tutorials that could be found online for first timers in the initial set up process, tutorials on how to program onto the Arduino for those wishing to create, design and find new ways to interact with many objects. Arduino is highly accessibility and available for purchase with the software available to download for free online. So much ingenuity has sparked so much that one may able to decide to build a custom Arduino PCB with simple tutorials readily available online.

The Emotiv EPOC EEG reading headset capabilities of transmitted the Radio Frequency (RF) signals from the user and extract information such as cognitive thoughts and facial expressions and converting them into digital form to be processed and inquired is a major part of this project that must be absolutely achieved.

This neuro-sensing apparatus coupled with its FELT electrode EEG sensors which to be properly placed on the users head as detailed in the Headset section of the Hardware Overview, to process the brainwaves results once converted to digital form via wireless USB receivers connection to PC. On the PC is the Emotiv Application Programming Interface (API) post processing Emotiv EmoEngine that sends the brainwave results to the API functions in each of their respective suites. This process is shown in the figure below.

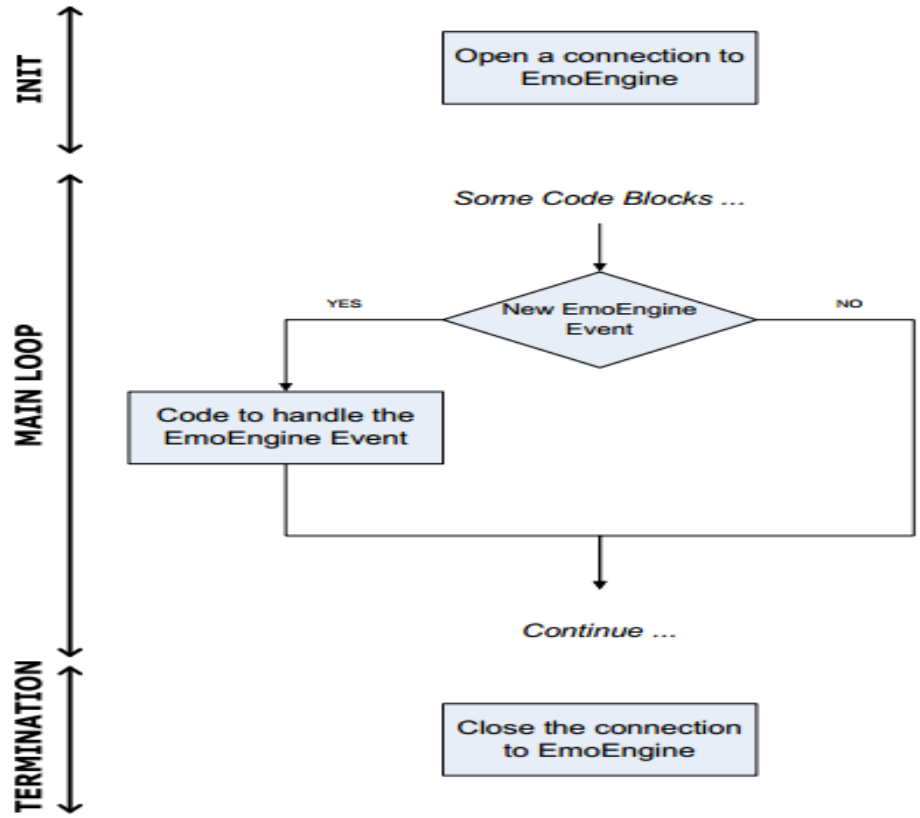


Figure 21 ***Using the API to communicate with the EmoEngine***

Figure 9.7 Flow diagram of Emotiv's API

The Suite's to be used are the Expressiv suite to accept handle events from facial detections to control lateral movements such as winking left to turn control left movements of the car and wink right expressions for right movements of the car. Also, the Cognitiv Suite will handle cognitive thoughts to control the motion of the car's backward and forward movements. Neutral signals will have no response to the car so there will be a slowdown to stop action. This is achieved by using the Emokey to map and translate the car to the each of their corresponding commands.

The state diagram below shows the flow of activities depending on event and actions to be taken for this event, depending on processed data of the headset by the EmoEngine.

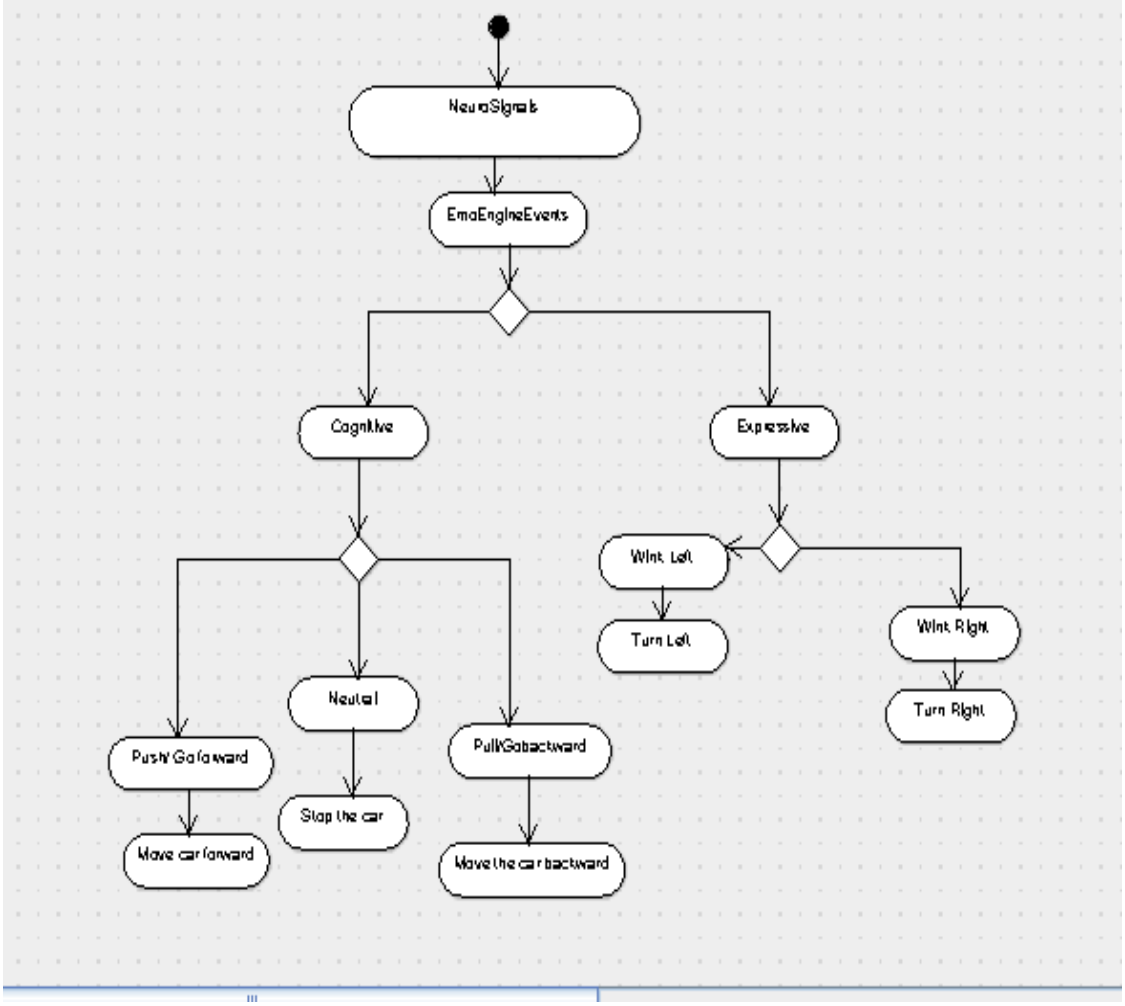


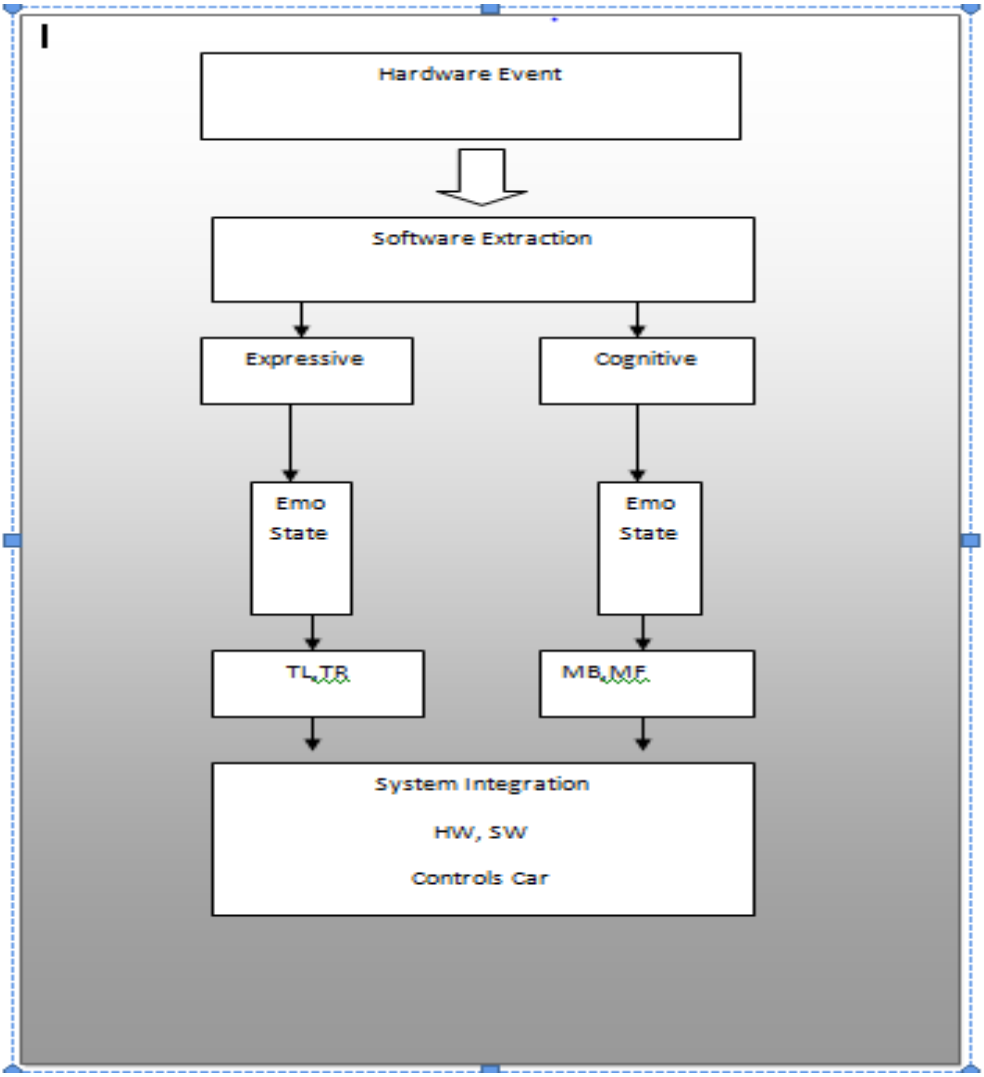
Figure 9.8 Data path for Emotiv

In is during these steps that EmoStates are evoked by the signals, the commands are handled by its corresponding EMOTIV API functions and methods that are built in, will be sent as string values to a translator program once the necessary information is gathered by the occurring event.

The chosen DH61AG core i3 mini-ITX motherboard as detailed in the Hardware Design section of this document given its specifications such as the USB which is needed for connections and communication between the headset' containing the read in brainwave information from the headset to the PC via USB transceivers to run the EMOTIV software. The connection between the motherboard and the PCB on the car is established thru the wireless transmitter in order to send information to be interpreted by the translator software program to control the car specifically, coordinating each desired response of the user of the headset's processed data with the corresponding action all with an operation frequency of

2.4 GHz and 1 GB of RAM. The processor outputs a parallel binary signal to the circuit. Also some other requirements is that when the input is 00000000 there is no voltage input, when it is 11111111 a positive 6 volts is applied and 01111111 means that the max negative output of -6 volts, with the most significant bit being used to determine positive and negative. This is achieved by an eight bit serial to parallel converter to control the circuits for the motor inside of the car with the Texas Instrument 74LV8153N which has a maximum data rate of 24 kbps.

The program will be written specifically in C++ to provide an object oriented interface between the hardware and software of this project. The interaction between the hardware and software in real time is a necessity. The hardware events, the predefined EmoState events (structures containing the information about the current state of the Emotiv detections) and the Suite-specific events from EmoEngine's processing the results of the Emotive headset using the Emotiv API library of built in functions are like modules or classes in C++ enabling code and software applications to be written which can manage, translate and communicate results. The data structure of the EmoState contains predefined EmoState values that's information being extracted by the C++ code to be written, which as explained earlier can designate control to the car to either Move Forward (MF), Move Backward (MB), Turn Left (TL), Turn Right (TR) or (Stop) SP by recognizing brain signals and corresponding with each of the commands processed from the user of the headset with Cognitiv Suit (cognitive) events Push/Think move Forward, Pull/Think to move backward or Expressiv Suite (expressive) events Wink Left, Right Wink or Neutral (no recognized thought) respectively.



Writing C++ code that sends this information and data stream of string information from the DH61AG Intel Core i3-3220 motherboard (containing EmoEngine and Emotive software API) to the ATmega328 microcontroller embedded onto the Arduino PCB that stores the software to be uploaded, converted and then translating them to a new eight bit binary signal to be recognized by the car built via (serially communicating) serial and parallel receivers and transreciever communication between the mother board to the Arduino, Arduino to the motherboard , and motherboard to the electrical sensing car all in real time makes this function possible, linking and hardware and software co design. The overall procedure of our project is dependent upon the co design of hardware and software, obtaining accurate results and desired actions or responses as defined by our system requirements given the constraints of the interaction between the hardware and software.

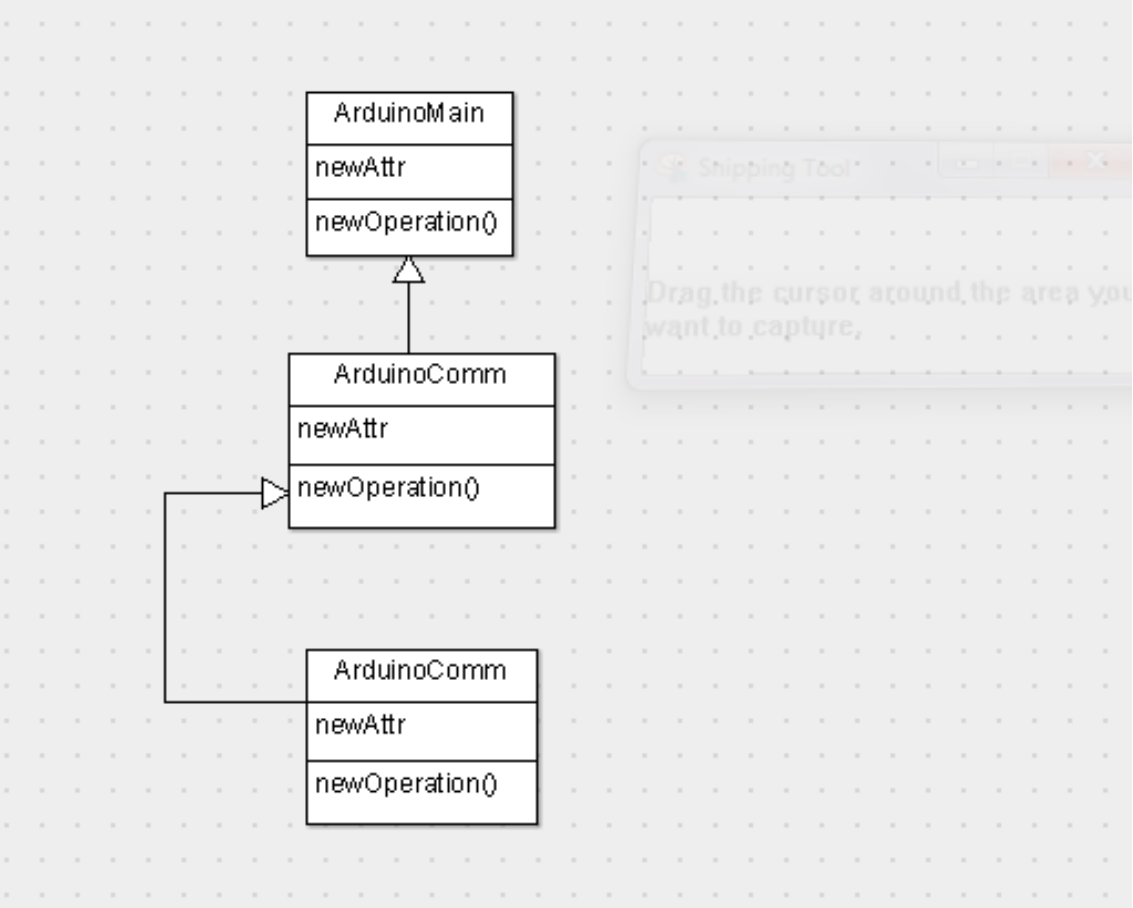
The C++ code specific for the Arduino as discussed in the Arduino section of document functioning as this translation process (translating the extracted stream

of strings from the EmoState data structure information – bit by bit) can be modeled also using the classes' data structure of the object oriented way of design of the C++ library for the hardware & software design demands of the project.

Class	Method	Expanation
ArduinoMain	StartComm()	Starts the communication process between motherboard and Arduino, instantiates ArduinoComm class
ArduinoComm	ArduinoOpen()	Opens ports and sockets for communication between the motherboard and the Arduino PCB microcontroller
	Arduinobegin()	Sets the data transfer rate for the serial data transmission
	Arduino_bitRead()	Receives and reads bytes extracted information exported from thr ExportSignal of the Sender class from the open serial port containing
	ArduinoDisplaybytes()	Displays the bits of data received
	ArduinoEnd()	Ends serial communication
	Arduino_bitSend()	Sends unique byte that was assigned to each pair bytes recognized as a different command from the translation scheme; instantiates ArduinoTranslate class
ArduinoTranslate	ASCII()	Obtains the ASCII value for the corresponding byte read
	Compare()	Compares the ASCII value of the byte obtained to the commands that can be recognized i.e. MF,MB etc.

	Assign()	Assign a unique binary code to the recognized and corresponding command that is read

The table above describes typical class data structure along with the expected method functions that will be used for each class. This describes the overall object oriented software design of the C++ code specific to the Arduino and the algorithm to be written to allow the correct and effective translation mechanism for the project. The objects creating in each of the classes listed above such as the Arduino Communication and Arduino Translated each use different each uses functions provided by and similar to that of the Arduino software programming language. For instance the methods described in the Arduino Communication class is similar to the functions used by the serial library that uses begin, end, print, and read bytes functions to set data rates, enable/disable serial communication, print messages and data and read characters from the serial ports. So similarities between the Arduino programming language (wiring based) and the objected oriented C++ code can drawn out to show the hardware software co design of the project. The Arduino code as detailed in the Arduino section of this document is essentially C++ functions that can be called from the code to be written. This is made possible by installing the Arduino libraries which contains a collection of codes that makes possible connections between the Arduino PCB and the motherboard to run the code.



The information to be extracted is contained inside the EmoState data structure and by being processed by each of their respective handlers after the necessary handler is determined by using the correlated methods. Once the Export Signal method from the Sender class is called and sends the extracted information and this information is obtained by the Arduino via sockets with functions StartComm, ArduinoOpen and ArduinoBegin being called once the program in the Arduino is uploaded. Then Arduino_bitRead reads in the data one bit at a time and can be displayed using the ArduinoDisplaybytes function. The stream of data string information will be read in character by character one bit at a time into a buffer on the microntroller. Each pair of characters read will be used to determine the event that was read by the user and used as a command with a binary signal that will be sent back to the mother board.

To conform to the specifications imposed by the requirements of both the Emotiv EPOC EEG reading headset and the DH61AG core i3 mini-ITX motherboard a custom Arduino PCB will be created that will have the ATmega328 microcontroller embedded onto it. This allows the Arduino to functions as an interactive device using its input and output port sensor signals to enable data to be communicated between the Arduino and the motherboard. However, the functioning Arduino uses a serial port on the controller in order to process the data it has received and to also send data bit by bit via USB. Due to this directly

sending new data to the car is difficult since it needs parallel signals. Below is a figure of a reference Arduino PCB with ATmega328 microcontroller. This is just a reference to the Arduino that will be built for this project.

Figure 9.9 Reference Arduino board

Instead with the Arduino socket connections that are provided enabled, data can be received directly and sent between the motherboard and the microcontroller. Once the data is received the Arduino can translate the information into an eight bit binary stream which contains the relevant information of the sent EmoState back to the motherboard. Having the Arduino PCB with ATmega328 microcontroller contain the software program to be written to translate the eight bit binary stream it received as input.

Since the microcontroller is preprogrammed with Arduino software which is also uses C++ and is easy to use to write a sketch program that can be compiled and uploaded to the microcontroller and be easily be reset manually it was determined that the Arduino was compatible. Also the cost, vast amount of online resources or references and the option to make a custom Arduino made this a very great choice.

The translated new eight bit binary being sent back to the motherboard satisfies the requirement of a communication between the motherboard that contains the USB receiver to receive headset data and the EmoEngine running EMOTIV API software and procedures, and the Arduino PCB containing the software. Once the new eight bit binary received back into the motherboard will then be sent to the car through wireless connection using an eight bit serial to parallel converter.

10 Design Summary of Hardware

10.1: Design Summary of Hardware

10.1.1: RC Car Hardware Design Overview

One of the most important aspects of this project is the electrical design of the car. It is first necessary to identify the basic structure and how every component will need to work together to perform the given task. The information will start with the headset and that will be sent to the processor on the motherboard. This motherboard will be housed inside of a small box in order to extend the range of the headset to the vehicle. Otherwise the headset range is only 5 feet and would not work well for the scope of this project. The motherboard will then transmit the signals to the arduino which will translate the information. That information will then be sent back to the motherboard. This signal then is sent via wireless transmitter to the custom pcb on the vehicle. This custom pcb will house the serial to parallel converter that will then tell the DC drive motor to drive forward or backwards and the DC servo motor to turn left or right.

The processor will need to accept input from the usb transceiver which also received information from the EMOTIV headset. That input will then need to be interpreted on the processor and sent to the Arduino to be used to control the various functions of the vehicle. Once the Arduino interprets these values and converts them into single eight bit binary values, it will then send those values back to the processor. From there the processor will send them out via wireless transmitter to a receiver located on the custom made pcb located on the vehicle. This input will then be interpreted by the series to parallel converter. This will output an eight bit value which will allow the DC drive motor to drive forward, backwards, or stop. It will also be used to control the car by turning left or right by utilizing the servo motor. There will also be information from the ultrasonic sensor that will be used to make the vehicle stop if it comes within a certain range of any object. The ultrasonic piezoelectric proximity sensor will be wired directly to the series to parallel convertor. When an object is detected, it will give a value of 00000000, which in essence turns the vehicle motors off. The following block diagram depicts the basic process of the vehicle.

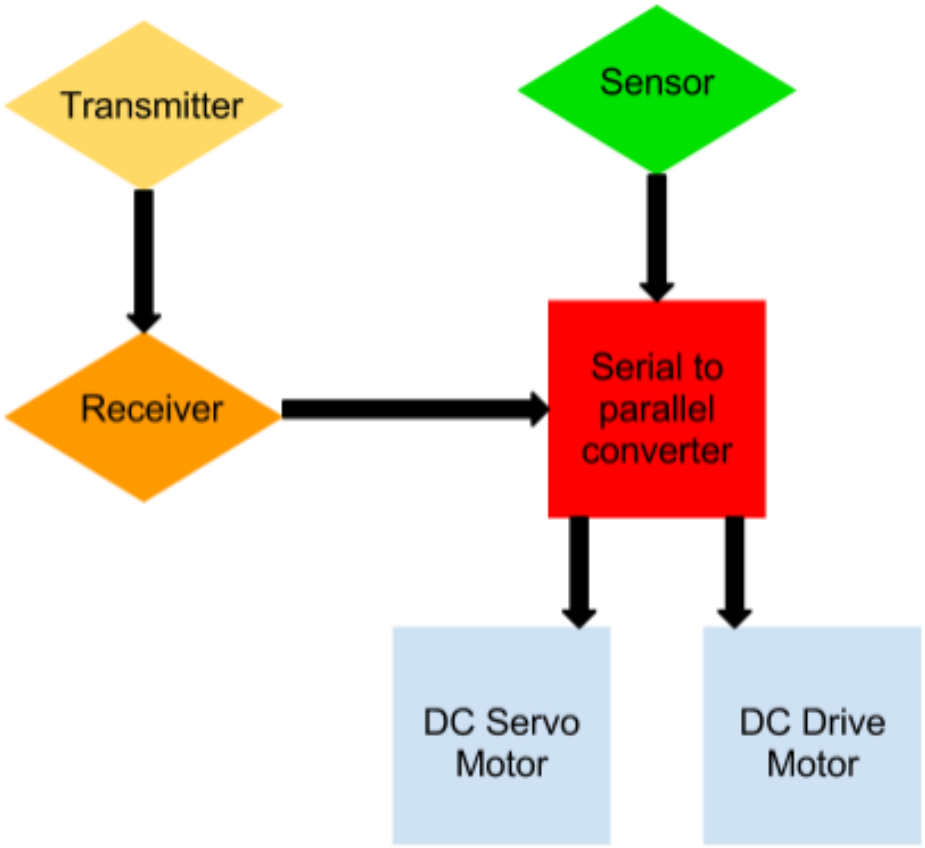


Figure 10.1.1
Vehicle Electrical Overview

Specifically, coming from the batteries, there will be the ultrasonic sensor and three voltage regulators with each one connected to a separate component. The ultrasonic sensor will be connected from the battery to the processor. The processor can then decide if the vehicle is within a safe range and proceed from there. The first voltage regulator will simply be connected to the processor and will step down the voltage to a value that can be used. The second voltage regulator will go from the batteries to the DC drive motor and will need to vary in voltage depending on a specific input given from the processor. The third and final voltage regulator will control the DC servo motor and will also need to vary in voltage based on a given input from the processor. The block diagram in figure 10.1.2 offers a more detailed and clear view.

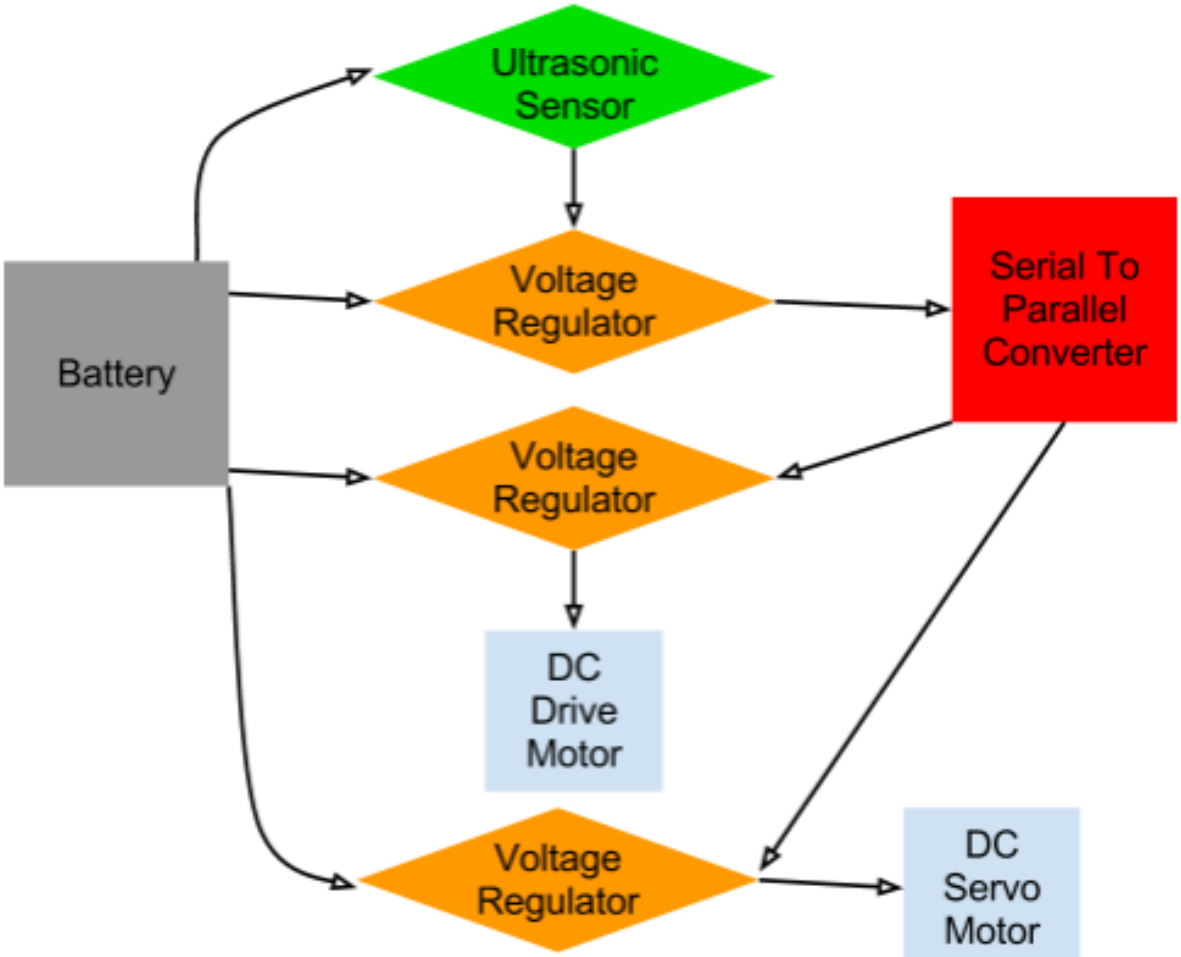


Figure 10.1.2
Power Overview

The piezoelectric ultrasonic sensor will be set to detect objects within 5 inches to allow for proper reaction time. This way, it will never encounter objects to harm the integrity of the vehicle. The sensor sends out pulses, if the sensor finds that an object is within this range it will send that information to the processor. The processor will then stop the DC drive motor from running. The block diagram in figure 10.1.3 offers a more detailed and clear view of this.

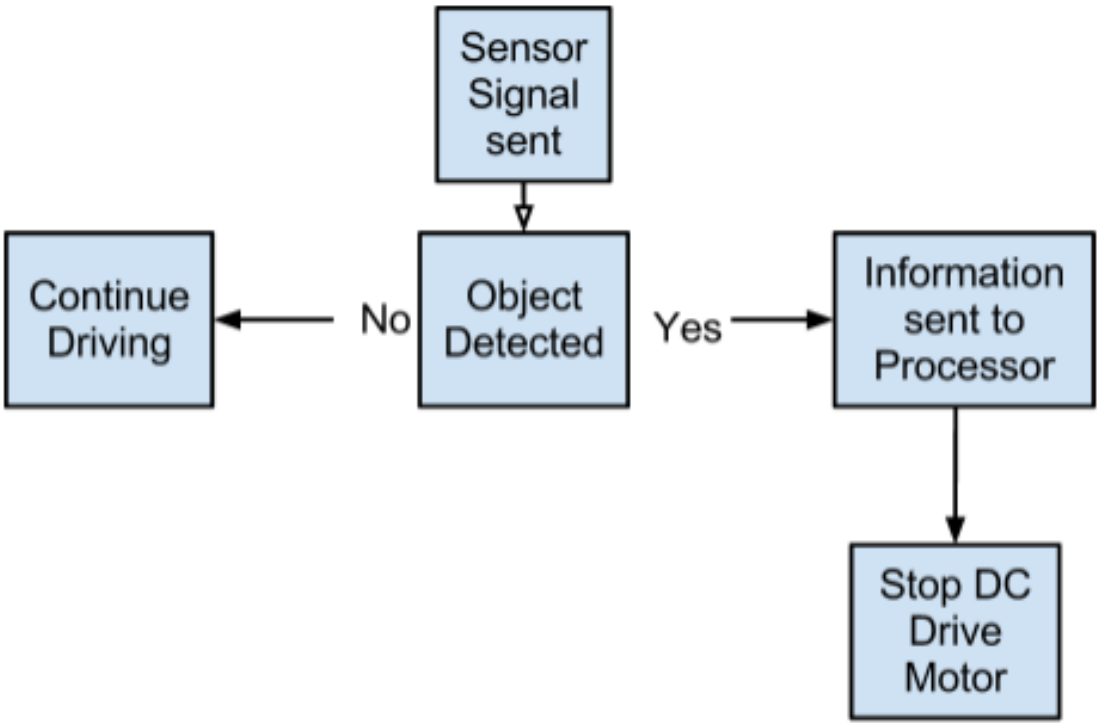


Figure 10.1.3
Sensor Process Overview

10.1.2: RC Car Processor Overview

The basic structure of the Processor is to collect data from the headset, through the transceiver, and from the ultrasonic piezoelectric sensor. Following this collection of data, it is important to analyze the data and determine whether the information is significant. If the information received is significant and causes a change, the processor then sends that new signal to each of the affected components. For instance, if an object is detected in the specified range of the sensor, that signal will then be sent to the processor.

The processor will then use that received information and send thus another signal to the serial to parallel converter. That then sends out an eight bit signal of 00000000, which tells the DC drive motor to stop running. The processor will also receive the input from the transceiver which receives input from the headset. That information will then be sent to a program in the processor to be decoded. Depending on the given input, the processor will either send a signal to the DC servo motor to turn left or right a certain amount of degrees. Or, the DC drive motor will simply go forward or stop altogether.

The last step that the processor will do is to update and clear the necessary information to make way for the new incoming information. The following figure 10.1.4 offers a basic flowchart for a more clear understanding of how the processor works from a hardware point of view.

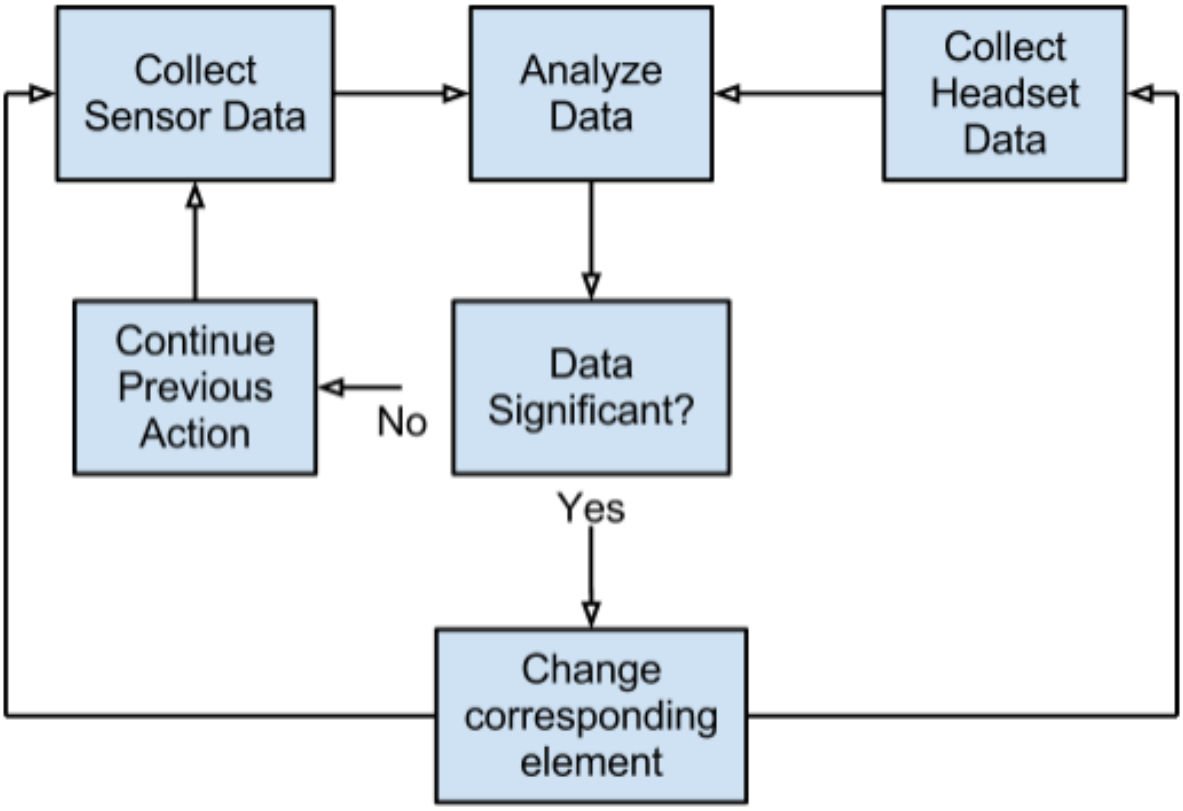


Figure 10.1.4
Processor Hardware Overview

In order to begin, there will first need to be a location in the memory where all of the data received is stored. An array, each of length three, will be used to store the data from the DC drive motor, the DC servo motor, and the piezoelectric ultrasonic proximity sensor. In addition to this, there will need to be two more arrays to hold the information for the control of the vehicle. Specifically, the arrays will hold two separate elements being the new information and the old information. There will also need to be a buffer that receives the input from the headset.

Data communication between the EMOTIV headset and the remote controlled car will take place through the USB receiver and the processor. The given USB receives the headset data and transmits that data in a serial fashion to the processor. From there, the remote controlled car will transmit 1 byte for the sensor data, 3 bytes for a voltage reading from across the DC drive motor, and another 3 bytes corresponding to the voltage reading for the battery power of the power source operating the controls of the remote controlled car. Three bytes is more than sufficient enough for each individual voltage reading because then there can be 512 different unique values represented.

In addition to these memory locations, there will need to be a set of functions that are called along the way in order to break this seemingly daunting task into smaller, more approachable tasks. A function will be created to read the sensor values and the information received from the headset. It will also compare the new data that is collected with the previous data. This function will then return an answer as to whether the data is different enough to change a movement on the car.

After each of the individual component readings have been taken and the new information has been stored in each of the individual memory locations. Then it will be necessary to analyze this given data. This analysis will take these new values and compare them with the old averages to see if there is a difference. All of the new averages will be used to go to the output buffer. In the case that the values are not different enough from the previous values, there will be no change to the vehicle and the previous task will continue.

10.1.3: RC Car RF Interference Overview

There are many environmental issues in RF communication which include many uncontrollable concerns. Among these are the weather such as rain, snow, heat, signal obstruction, etc. These should not be of concern for the aspect of this project though. There is no snow in Florida, so this would not ever be a problem. The remote controlled vehicle would never be driven in the rain and heat should not be of any concern so long as the car is properly insulated. Given all of these precautions, it is impossible to completely eliminate noise or avoid complete obstruction of the signal between the transceiver and the headset and the vehicle. This being said, it is important to use the headset and the vehicle within the specified range given with the EMOTIV headset in order to reduce as much interference as possible. To design our own transceiver would be impractical, it would cost much more than the budget allows and would most likely sacrifice efficiency, range, and size. Therefore, the USB receiver that came with the headset will be used.

Synchronization must take place to ensure that communication between each of the devices is effective. Each component must be awaiting the moment when it receives data, to submit said data, and know exactly what to do with all of the data. All of this will be accounted for under the integration process with its respective programming platform. Synchronization can not take place when there are significant radio frequency interferences, a lack of battery power, or physically blocked transmissions. Thus a connection would not be able to be established and the corresponding control operations could not be executed.

10.1.4: RC Car Structural Modification Overview

Since the remote controlled car is being purchased instead of being made from scratch, some basic structural modifications will need to take place in order for each of the necessary components to be properly and safely fastened. The piezoelectric ultrasonic proximity sensor that will detect objects in the vehicles way and will need to be attached to the front of the vehicle where the headlights are located. In addition to this, in order to properly mount the processor, PCB, and batteries, the entire plastic body of the vehicle will need to be detached. Since the vehicle will be purchased already manufactured, the positions of the DC drive motor and the DC servo motor should not be changed in any way. The actual DC drive motor and servo motor parts and connecting wires will however

be changed. The PCB for the DC drive and servo motors will be mounted a few inches away from the actual motors. This way it will prevent as much damped feedback as possible. The processor will be placed as far as possible from the DC drive and servo motors in order to minimize interference. It will also be placed close to the edge of the vehicle so that the attached usb flash drive receiver will have an adequate amount of room and will not interfere with any of the other components. Another necessary structural modification will be to create some more space for the added battery inside the vehicle. The current space is not large enough to accommodate both of the required batteries to run the vehicle and all the necessary added components.

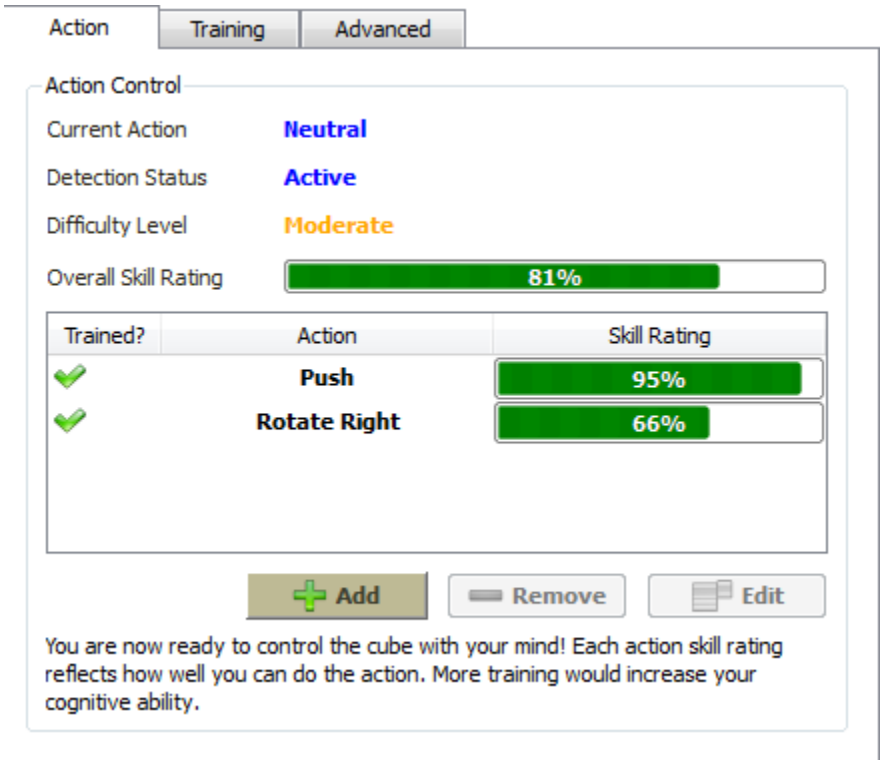
10.1.4.1 Structural Modification Process

In order to properly secure the various components to the vehicle, proper precautions must be taken. Four small screws will be used in order to fasten the PCB to the frame of the vehicle to ensure stability. The piezoelectric ultrasonic proximity sensor and the MOSFET that will be used to power the motor will also need to be securely fastened to the vehicle. A heat sink for the MOSFET will be necessary and physically mounted to the vehicles chassis using four small screws. In addition to this, the batteries used to power everything will need to be securely fastened so that the vehicle will always run properly. The batteries will be stacked into the cavity that will be made in the vehicle and sealed in place. The receiver will also need to be securely mounted onto the vehicle by use of soldering onto the printed circuit board, which will be located in the bed of the truck that is being used. This will allow the circuit board to be out of the way of any of the parts that allow the vehicle to move.

11. Project Testing

11.1 Headset Testing

For initial testing and training for the headset, many different approaches were taken to ensure the optimal performance.



(Figure 11.1.) Final training skill rating for both the push and rotate actions.

Initial training on the headset was conducted by using the Cognitiv suite and simply trying to figure out how to move the 3D cube at first. Simple tests were conducted to try and establish an adequate “neutral” state, such as listening to relaxing music. This approach wound up producing a relatively noisy neutral base line due to the fact that the music was causing brain activity towards the back middle of the scull. The second approach was to sit in a quiet room and look out a window. This resulted in a fairly stable neutral state, but when training began on trying to push the cube, the neutral signal was still too noisy to detect initial attempts to push the cube. For the 3rd attempt to establish a clean neutral state, the headset was worn in a room with no light and as little outside noise as

possible. This produced an ideal neutral state from which all other signals would be more easily registered.

After the neutral state was established, pushing the cube was the first action imposed on the cube. Since this was the first recorded action any brain activity could be recorded to push the cube, but this activity had to be refined to a single thought or concentrating on a specific thought. Difficulty followed training due to the fact that it was initially hard to visualize that specific thought pattern, so a physical movement was introduced to associate with that thought. A slight up or down movement of the head while having the user's eye fixed on the cube became the easiest to associate with the push action. After a few training session the push skill for the Cognitive suite was recorded at 95% efficient at detecting the specific thought pattern.

As stated in previous sections adding more actions for the cube to preform dramatically increased the difficulty of produce that action. After mastering the "push" action, rotate right was the next action to be added. Trying to coming up with a new thought process, at first, only wound up, only just, activating the push action, so it was determined from the research outlined in section 4, that an external stimulus would work to produce different signal patterns in different areas of the brain, specifically the somatosensory association cortex. Among methods tried; were having the user experience a sudden temperature change on an extremity. This produced results but not ones stable enough or ones that lasted long enough to rotate the cube as desired. Playing different genres of music a different volume levels was also tried, but all auditory responses were erratic and did not produce a stable enough signal, this was attributed to a changing of the beat and tempo of the music. It was later researched as explained in section 4, that while the brain is listening to music the chemical dopamine is released, which makes us feel pleasure and euphoria. Because of the music the EEG reading produced were in a raised state but we unstable because as the music got more or less intense, the amount of dopamine released varied.

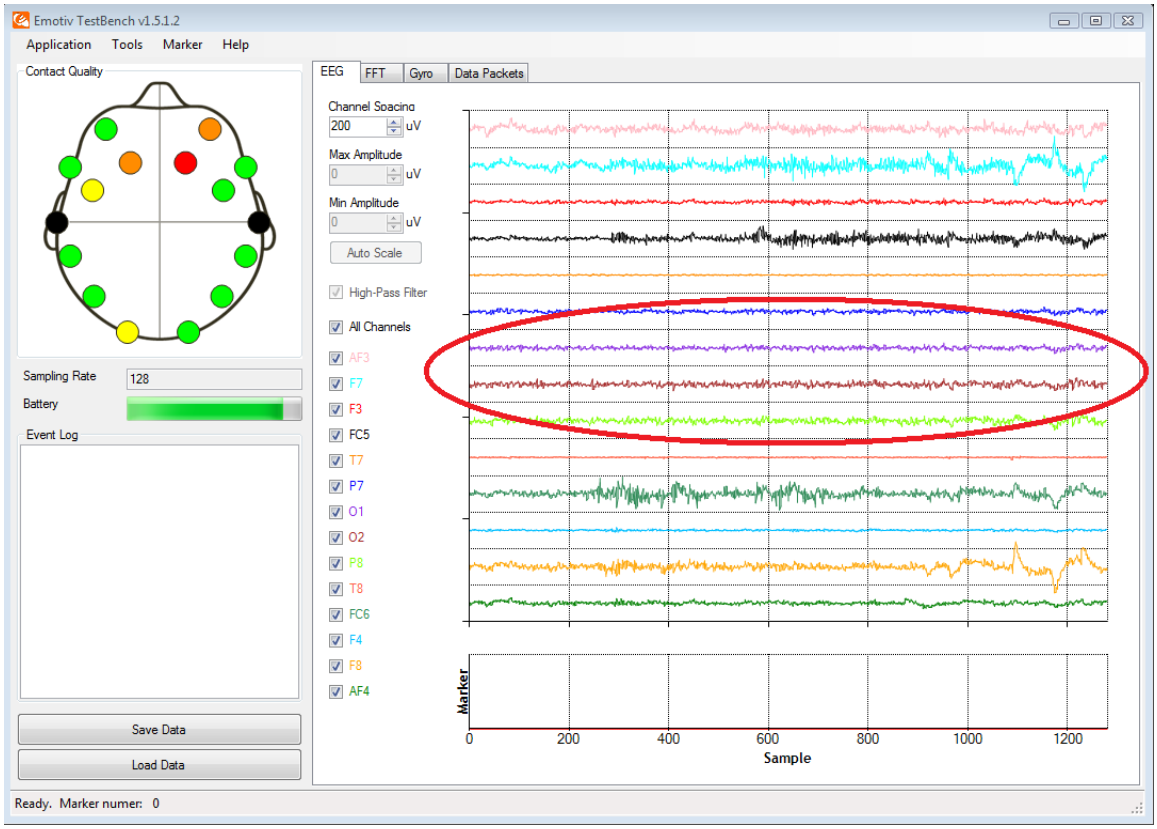


Figure 11.2 Pain produces steady, elevated readings from sensors P7, P8, O1, and O2. Which is what was necessary for continuously rotating the cube.

It was found that pain produced a very distinct and strong signal for rotating the cube. And having the user wear a shoe with a thumb tack placed under the big toe (due to the high concentration of nerve endings and large surface area there), registered on the O1, O2, P8, and P7 sensors, right over the somatosensory association cortex. This method of getting an alternative brain pattern was comically referred to as the “Ocean’s 11” technique.

To the tester’s surprise and delight, after training for a time with the tack it could be seen that by simply looking at the shoe with the tack in relatively close proximity to the foot that was originally on; the same signal patterns were seen without the tack ever making contact with the toe. It was noted that by associating the tacked shoe with pain, the brain responded the same as if the finger was in pain as described in section 4.3.3.

INFLICTING ANY MAJOR OR PERMANENT PERSONAL INJURY WAS NOT DONE FOR CONDUCTING ANY OF THE TESTS PREFORMED.

11.2 Software Testing

The software to be produced is one that is capable of translating from the electrical sensing circuit box located on car the acquired neuro-signals and use these RF electrical signals as inputs to control a remotely an RC car that is designed. The software on this box translates the EEG signals into an FR signal that will be interpreted to the four basic directive actions commands – left, right, forward and backward. These commands are shown below:

Event Name	Internal Stimulus	External Responses & Description of event	Internal data and State
Turn left Wink left	Think left	Moves the RC car a certain degrees towards the left direction	
Turn Right Wink Right	Think right	Moves the RC car a set degrees to the right	
Move forward	Think go move up/ forward	Speeds up and Accelerates the RC car by a preset speed	
Move backward	Think move back/ backward	Decelerates the RC car by a set amount of speed defined , reverses its current direction	
Stop	Stop thinking	Decelerates the RC car by a predefined speed and slows it down to a complete stop	

(Table 11.1.) Table of Expected events to occur with response to coordinate corresponding actions

Some overviews of the software are knowledge of programming languages such as C and C++ in order to provide correct feedback controls. 2.4 GHz Intel Pentium 4 processor (or equivalent), Microsoft Windows XP with Service Pack 2, Windows Vista or Windows 7, 1 GB of RAM, 50MB disk space available and One or Two unused USB 2.0 ports are some of the minimum System Requirements for the Emotiv EPOC SDK. Also EDK.dll must be installed in order for an Application created by Emotiv EmoEngine and Microsoft Visual Studio 2005 (VC 8.0.CRT version 8.0.50727.762 or later) SP1. Please see user's manual from emotiv.com for details.

There are a number of events to be expected and handled as outlined by the table above. Each event is grouped to their respective suites. Depending on the type of detection groups there are associated with either EMOTIV's Cognitive suite or the Expressive suite. The Cognitiv detection group which houses the methods and functions to handle the cognitive type events from the headset are grouped within the EMOTIV API's Cognitiv Suite. This is similar to how the Expressiv detection group holds the functions to handle all facial expressive type events received which are in EMOTIV API's Expressiv Suite. Thus the Cognitive detection group handles the events such as commands to think forward movement or a forward push, think backward movement or pull and a neutral command which is to stop. Similarly, The Expressive detection group handles commands relevant to facial expressions such as winking left and winking right. Thinking to move the car forward, stopping or making the car go backward or alternatively winking left or right, are extensively relative to each of their respective or commands just as each command are inclusive to their respective suits as shown in the diagram below.

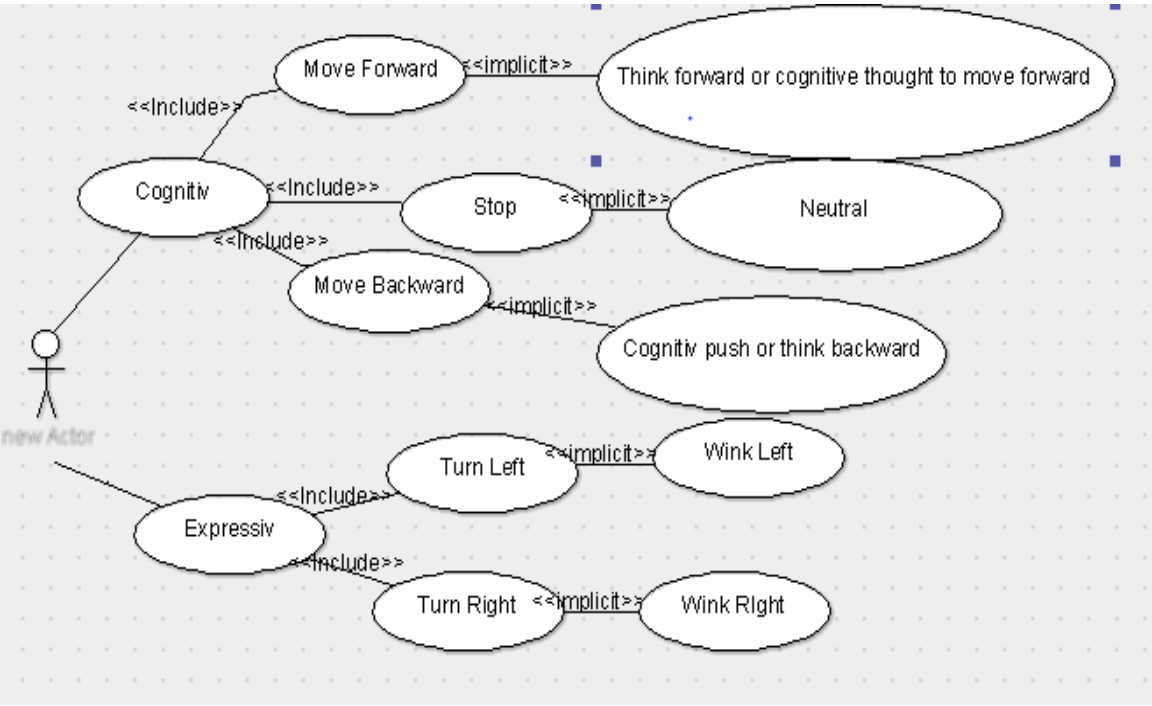


Figure 11.2.1 Case Diagram

Inputs and Outputs will be evaluated based upon the expectations of each API function's return statements and values and consistent arguments for inputs. Also to be made in the software testing activity is test performance, bugs reports and design. The test must demonstrate a working and completed software by repeated test runs with various test cases which may include different input arguments. What demonstrates working software is each user command corresponds to the desired response. So the software must be able to translate EEG signal into corresponding events which must then provide that specific event as a control for the RC car to move turn left, right, and move forwards or backwards and etc.

This software must function as an extension of the user. The software provides the key to control a car that responds to the users' brain activity. The car movements must be according to the brain activity. Testing will based on this principle in that the software is to conform to specifications required of this project.

An application will be written in C or C ++ that uses the Emotiv API (Application programming interface). The API consists of Emotiv data structures such as the EmoState which contains the current state of the Emotiv Detections. The EmoState is the result of communication between the Emotiv EEG (electroencephalography) Neuroheadset and the EmoEngine which receives the preprocessed EEG and gyroscope data, and then performs post processing – translating the Emotiv detection results. The information contained inside the EmoState can be used for in both the Emotiv detection suites (e.g. the Affectiv

Suite and Cognitive Suite). The users' facial expressions are monitored through Expressiv Suite as the Cognitiv Suite measures and interprets conscious thoughts all in real time.

In order to establish connection between the EmoEngine – EE_EngineConnect or EE_EngineRemoteConnect is called depending on the headset used and the connection is closed by calling EE_EngineDisconnnect(). EE_EngineDisconnect() must be called before the end of the running application EmoState are triggered through events such as EmoStateHandle and EmoEngineEventHandle. EE_EmoEngineEventCreate allocates the corresponding Emotiv API functions and EmoEngineEventFree frees and dealocates memory from an allocated and newly created event. EE_EmoEngineEventGetEmoState() and EE_EmoStateUpdated retrieves the changes in states of users. EE_UserAdded monitors input devices and EE_CognitivEvent is for the Cognitiv Suite. EE_EngineGetNextEvent() retrieves events that are called by the EmoEngine in order to communicate with the running application. The following sequence diagram is used to show this process

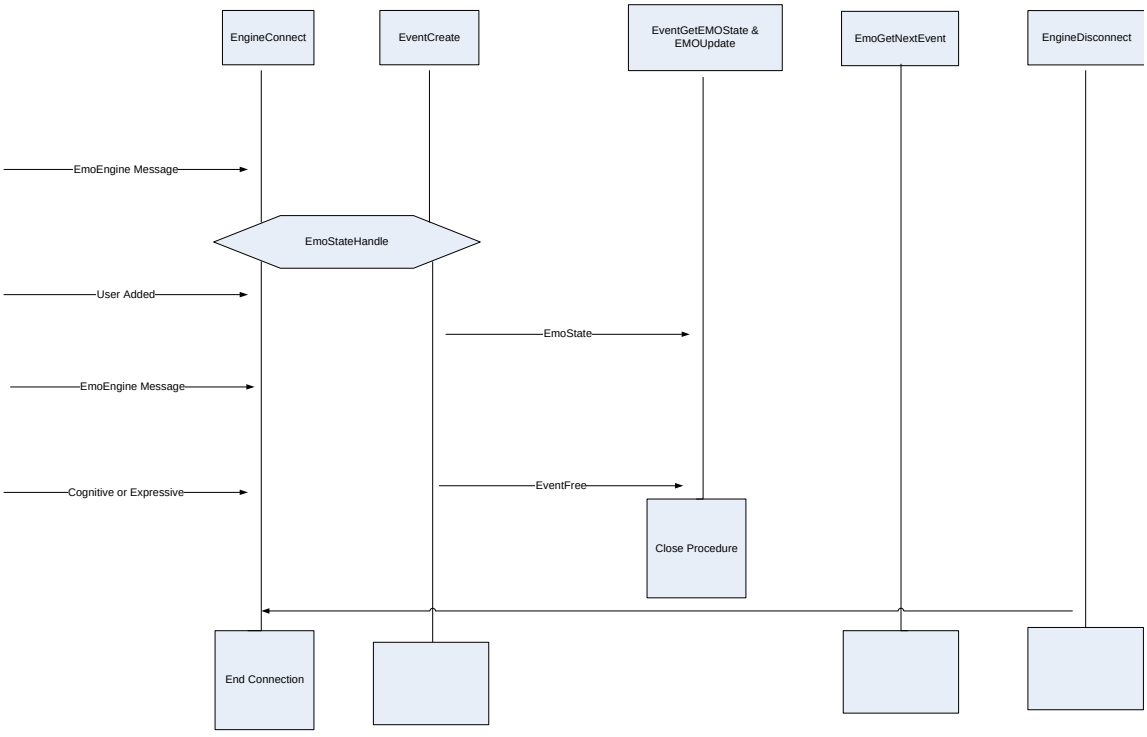


Figure 11.3 Sequence Diagram for Application Communication

The types of events to be handled are Hardware-related events, New Emostate events and Suite-specific events. These events relate to communication between Emotiv input devices and computer, cognitive states and facial expressions, and configuration to Expressiv detection suites respectively.

In our Application will utilize both the Expressiv Suite for facial expression recognition and the Cognitiv Suite for cognitive measurements. In the Expressiv Suite the following Emotiv API functions will be used to acquire the task of reading the users' facial expression ES_ExpressivGetUpperFaceAction(eState) : reads upper facial action , ES_ExpressivGetLowerFaceAction(eState) : reads lower face action. The ES_ExpressivGetUpperFaceActionPower(eState) and the ES_ExpressivGetLowerFaceActionPower(eState) functions measures the respective strengths of each facial expression. We will also record eyelid movement with ES_ExpressivIsBlink(), ES_ExpressivIsLeftWink(), ES_ExpressivIsLookingRight(), etc. These Emotiv API functions returns an integer value or EDK_OK for a successful API function or Error codes. A class diagram is shown in the figure below to show each of the Expressive suits functions relations with to the EmoState that generated this suite.

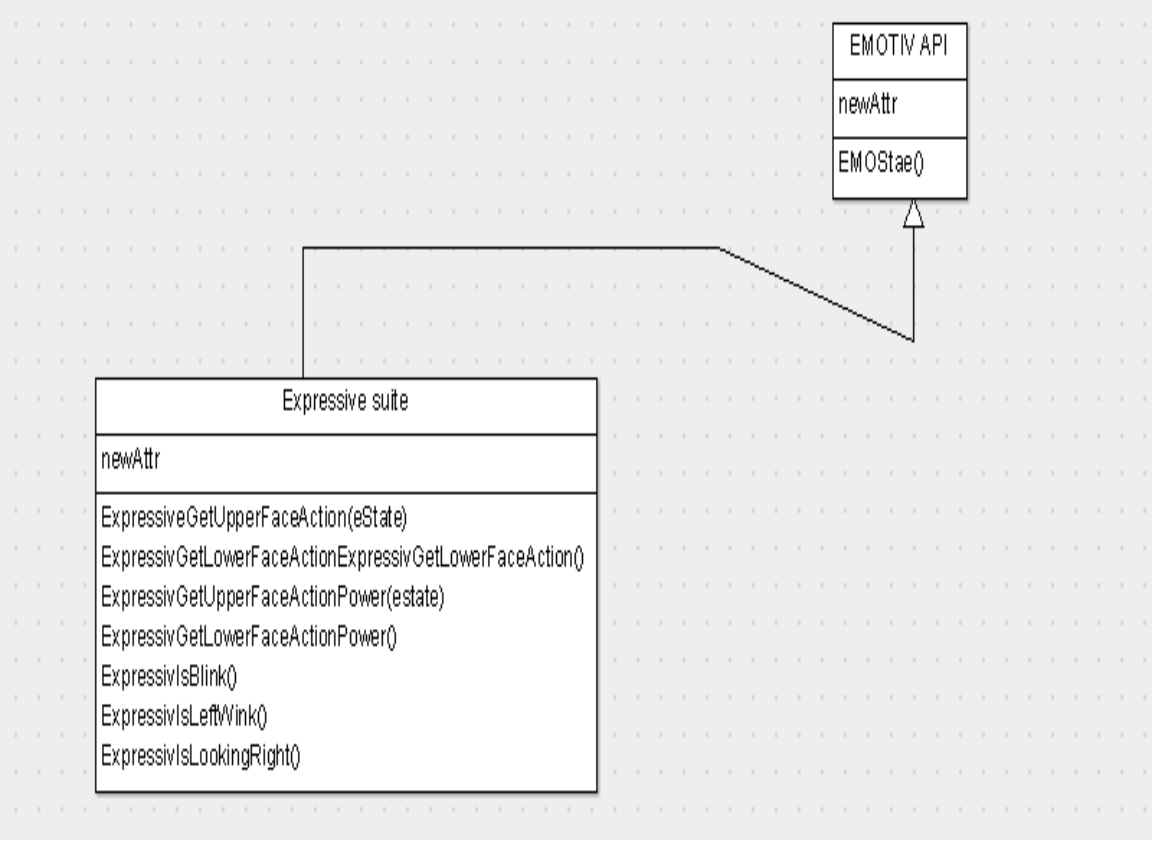


Figure 11.4 Emotiv syntax for expressions and corresponding values. (Used with permission from Emotiv.)

Figure 11.4 (Table 3) from the Developers SDK User Manual shows the syntax to some expressions and there corresponding values for each expression type. Also are a listed of events from the user's manual.

Expressiv™ action type	Corresponding ASCII Text (case sensitive)	Amplitude value
Blink	B	n/a
Wink left	l	n/a
Wink right	r	n/a
Look left	L	n/a
Look right	R	n/a
Eyebrow	b	0 to 100 integer
Smile	S	0 to 100 integer
Clench	G	0 to 100 integer

Figure 11.5 Syntax for expressions in Emotive language.(Used with permission from Emotiv)

For the Cognitiv Suite uses API functions such as ES_CognitivGetCurrentAction(), and ES_CognitivGetCurrentActionPower() similar to Expressiv Suite commands but instead monitors conscious mental thoughts.The figure below shows the events according to each of their respective detection groups. In the figure below is a more detatailed view relationships with each API function and each of their respective suites.

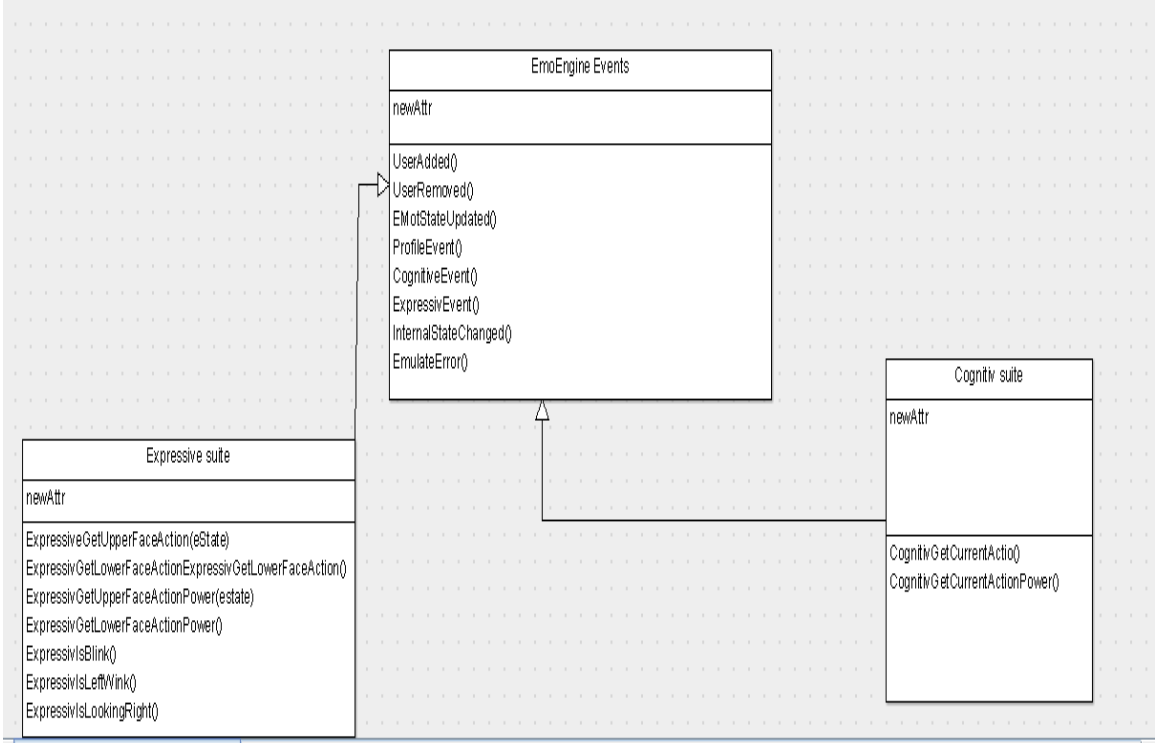


Figure 11.6 API functions associated with their respective suites.

In order to test every aspect of this software, it will be important to include unit tests, integration testing and system testing. Before any tests are done with the physical headset, all the software will be tested using the Emotiv EmoComposer. This is an emulator of the EmoEngine, which sends signals to the computer as if it were the actual headset. This will allow the software to be tested without any loss of signal or interference. Once the software is proven to work with the EmoComposer, then all the tests will be repeated using the physical headset.

The process of testing this project is intended to accomplish the following tasks:

a) Verify that all methods work as stated

b) Confirm that all signals are being received correctly

c) Assure that there are no bugs or unhandled exceptions in the code

d) Make certain that signals are being processed correctly

e) Confirm that the processor is sending the signals correctly to the car

Although it is very important to ensure that the software works correctly, these tests will not prove that any individual can use the prototype. This is due to the fact that the Emotiv EPOC headset requires much training to master, and

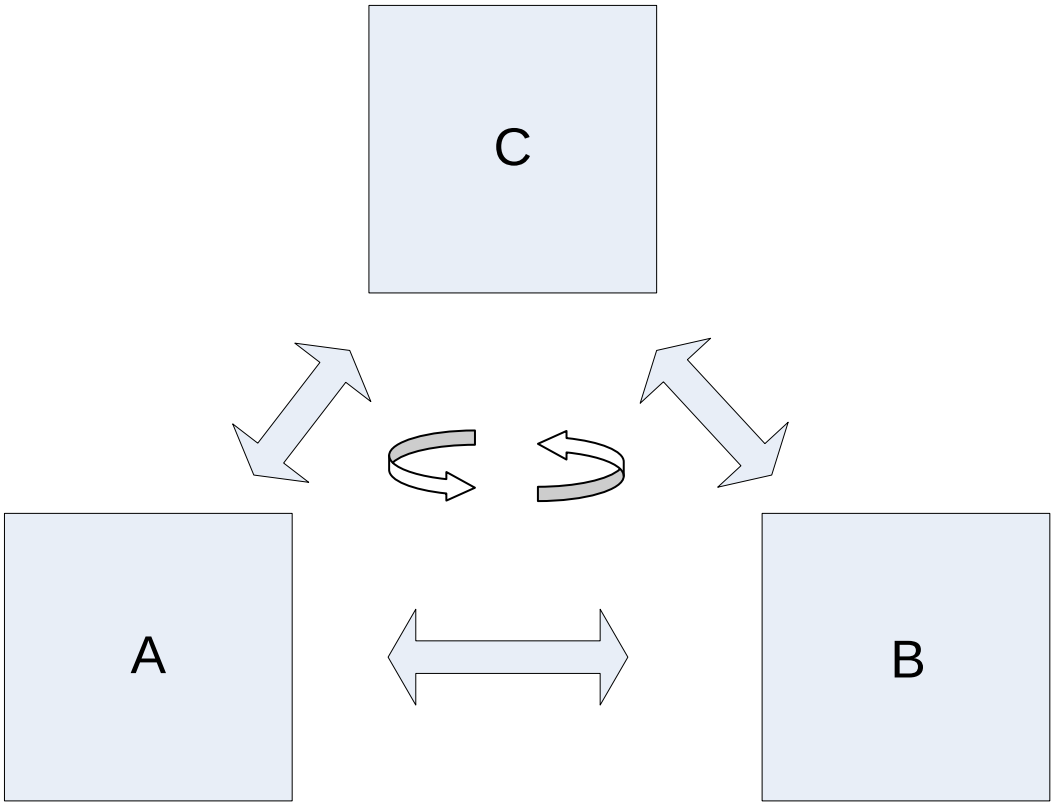
therefore it would not be possible to pick someone at random and have them test our project. However, it would be possible to verify that the software works as written by using the EmoComposer because then the tests will not require the tester to use the headset during the testing process.

The first tests that will be carried out will be the unit tests. These will be the earliest tests because they will consist of testing specific methods in the classes of this project. The unit tests will consist mostly of Assert statements, which will verify that the results received by a certain method are equivalent to the expected results. These unit tests will be placed in their own test classes that will be included in the source code.

In order to implement integration testing, generic parameters will be used in various classes to make sure that they are working together correctly. For example, the Dispatcher will be given sample data and it will be verified that it sends the signal to the correct handler. This will not include any communication between the mounted processor and the car.

The final test phase will consist of system testing. This will be the most important series of tests in which the headset will make a connection with the processor and signals will travel through the entire translation process, beginning with the headset and finishing with the processor sending the correct command. These tests will verify that the project not only performs normally, but can also handle unusual and unexpected scenarios. The process of system testing is shown visually below in Figure 11.7:

Figure 11.7: System Testing



This figure shows that all modules should be tested and unit tests should also be completed. This is necessary because it minimizes the difficulty in determine any sources of error if all modules have already been proven to work correctly. Each arrow signifies that testing of more than one module and the circular arrows in the middle signify a complete system test, involving all the modules put together.

11.3 Vehicle Testing

11.3.1 Individual Component Testing

It is very important to devise a system to adequately test the hardware on the vehicle. Each system, subsystem, and individual component must be tested in order to see if they work respectively. To get an accurate idea of how each of the components are working, all of the batteries, DC drive motor, DC servo motor, voltage regulators, piezoelectric ultrasonic proximity sensor, and receiver must be thoroughly tested.

The first item that must be tested is the battery. It will be run through five full charge cycles with a constant draw of 2 watts. This specific test will verify the capacity of the battery as that that was given. After this test is performed, a more adequate representation of the power output of the battery will be shown. This test will also be run five times and each value will be recorded. These tests will be run for both of the batteries. Assuming these batteries give the values that were specified from the manufacturer, the next steps can be taken.

The voltage regulator that will be used to control the voltage of the DC drive motor on the vehicle will also need to be tested. An eight bit binary input will be used and changed to each of the possible 256 values. These output voltage readings will then be recorded and compared to simulations that will be run. If the recorded values match those obtained in the simulations, the next tests can be started.

The DC drive motor that will control when the vehicle moves forward or backwards will be the next component to be tested. In order to safely test this, the voltage regulator will still need to be connected. Depending on the voltage applied to the motor, the resulting revolutions per minute will be recorded and subsequently plotted on a graph. The graph will show the revolutions per minute as a function of the voltage being supplied. It is important to test this after the DC drive motor is put into the vehicle because the weight of the vehicle will drastically change the results obtained. After the vehicle is fully assembled and functioning properly with all the components added, this test will be done again. This will give a better understanding of what the bounds of the motor are with all the other parts added and working as well.

The DC servo motor that will be used in controlling the direction that the vehicle turns will need to be tested next. The way that the servo motor works is that it is able to turn a certain amount of degrees depending on the applied voltage. In order to see exactly how much the DC servo motor turns a voltage test will need

to be done. Twenty possible inputs will be given varying from the minimum input voltage and ending at the maximum input voltage allowed. This will give a better understanding of exactly what the preferred input voltage will be to turn the vehicle the desired amount.

11.4 Arduino Testing

With the limitations and specific requirements given by the demands of this project the Arduino PCB ATmega328 microcontroller and its need to function as communication device between the motherboard that will be able to translate the information received into a signal to be used for the car. The design of the appropriate software to be programming into the microcontroller to function as this translator was obtained. The inputs arguments to be expected of the microcontroller are a string data that contains the information needed to interpret the command. The commands to be used are to move the car forward, backward, left, and right and to stop the car.

Commands containing move forward, move backward and stop responses are assigned the strings MF, MB and SP respectively. Just as for the Facial Expressive group commands contains Wink Left (WL) and Wink Right. The MF triggered event corresponds to moves the car forward, the MB event moves the car backward, SP stops the car, WL makes a left turn and the WR performs a left turn of the car.

The assigned string values that are attached to its relative command sent to the ATmega328 microcontroller. The objective of this software and test will be based on its ability to achieve its desired goal of converting this string into a unique and meaningful eight bit binary to be recognized by the car in order to perform the control. Knowing that each string is sent to the translator program bit by bit via serial USB of the Arduino PCB string a binary code is assigned by comparing with them to their equivalent ASCII. A unique binary value is then assigned each code. The new eight bit binary signal will be sent back to the motherboard. Arduino contains procedures and libraries that will be very useful to implementing this program.

Procedures such as Setup ( ) ,The loop ( ) function to iterates the statement , Arduino has control structures that may be used such as if, if...else, for, while , switch case, and return for conditional operations, control overflow, repeat code or loop conditionally and comparison operations will be used in the program.

Functions such as Bits and Bytes, Communication will be used in the translation program to read and write bits. The serial communication library will be of primary use for communication between the Arduino board and the motherboard. The software is compiled it is translated into binary data. Each bit is sent one at a time through a USB cable connection to the ATmega328 microcontroller of the Arduino PCB. The program will be stored in the ATmega328 microcontroller. Data is communicated between the Arduino and the motherboard. Arduino

receives the data and can translate the information into an eight bit binary stream back to the motherboard. Thus communication requirements are satisfied .

Listed below is a detailed Specific testing requirements for the Arduino Software

Requirement 1
Statement: Program will translate a stream of strings into a binary
Arduino software is the source
Depends on the EmoState
Possible communication conflicts between the board and PCB
This will be evaluated by the output and input arguments of the Arduino.

Requirement 2
Program shall handle strings as input
The source comes from the EmoState send procedure
Depends on input string value sent by send procedure
Conflicting data types may be a possible conflict
Evaluation Method: If the send sends a successful transmission message then the data has been sent and received successfully

Requirement 3
The software should handle the relevant string
Arduino translation scheme and ASCII
Depends on the method used, to assign unique values or just there ASCII values through comparison operations
No conflicts
The binary assignment should change and be unique for each individual string

Requirement 4
A unique Binary code should be assigned to each new individual event string
No source
Depends on the string value
No conflicts
Output result of the corresponding binary value should be displayed and check if it matches the desired binary

Requirement 5
New Binary must be sent back one bit at a time
No Source
Depends on Serial communication procedure
Some possible conflicts is communication between the motherboard and the the Arduino PCB
This is evaluated by checking if the motherboard received the signals (The TX pin should be lit for communication transfer data) and written back to the motherboard

The functional Requirements of the Arduino software are to load software embedded microcontroller, handle various string arguments, and to display data on Arduino's serial monitor. The software must interface with the input data arguments such as the strings MF, MB and etc. Also it must output the data which are binary versions of the strings reads serially. Expressive events are TL or TR strings and Cognitive events are MF, MB or SP. Data must be sent and received in a serial communication manner between the motherboard and the Arduino and each binary signal assigned to each of these event strings must be unique relative to one another. The software must run on the ATmega328 microcontroller and the transfer process should be responsive, performed in an adequate amount of time and easy to use.

In order to isolate possible errors and to verify the correct output and response as desired is acquired individual tests cases will be based off of each of the Emotiv API functions as well as the Arduino functions will be extensively tested with various test cases. This is to ensure correct communication and data is being communicated between each of the functions determining if the desired input and output is communicated. Test cases will be described by who ran the test, what function specifically was tested, when was it run and marked as either a success or fail depending on if the correct information;, signal or data has been communicated between relative functions. Success means that signals have been successfully communicated where as failure identifies incorrect data or no communication. Such informative can be obtained from the Emotiv API functions as each function has a signal to notify user if it's corresponding task has been achieved successfully with errors or EDK_OK signals type. This is shown in the table below.

Emotiv API function Library and Arduino Library function (expected functions to be used) and also Function and what was tested (based on its ability to do)	**Specific Suit Detection or Particular Software**	**Output or Evaluation method(success or fail)**	**Who tested and When**
EmoEngine (Communcitation with Emotiv neuroheadset, translates Emotiv Detection into an EmoState)			
EmoState(A datastructure containing info of current state of all activated Emotiv Detections)			
EE_EngineConnect (Connect App to EmoEngine) **EE_EngineDisconnect (disconnects connect between App and EmoEngine)** **EmoStateHandle (Alocates appropriate Emotiv API)** **EE_EmoEngineEventCreate (Creates a buffer for EmoEventHandler)** **EmoEngineEventFree(frees an allocated memory for emostate)** **EE_EmoStateUpdated(gets updates users facial expression and records the changes)** **EE_EngineGetNextEvent(asks the EMoEngine to get the current published EmoEngine event)**	Emotiv Engine not suite specific	String values to confirm success of failure EDK_OK for a successful API function or Error codes	Lee/ Chris

ES_ExpressivGetUpperFaceAction(eState)- **(reads upper facial action)** **ES_ExpressivGetLowerFaceAction(eState – (reads lower face action.)** **ES_ExpressivGetUpperFaceActionPower(eState)** **-(measures the intensity of each facial expression)** **ES_ExpressivGetLowerFaceActionPower(eState)** **ES_ExpressivIsLeftWink** **(records blink expression)** **ES_ExpressivIsLookingRight** **(records look right expression and action event)**	Expressiv suite	EDK_OK for a successful API function or Error codes	Lee/ Chris
	Cognitiv	EDK_OK for a successful API function or Error codes	
Receiver		Opens a connection between the mounted processor and car	Chris

Connect –(Opens a connection between the mounted processor and car) **ReceiveSignal – (Gets signal sent from the headset)** **CreateEvent - (Uses signal to make an EmoState)** **Dispatch – (Makes an instance of the Dispatcher class and handles the signal)** **Send –(Makes an instance of the Sender class and sends repeated signal straight to the car)** **DetermineHandler –(Receives an EmoState as a parameter and determines which handler is necessary)** **SendCognitiveHandler – (handles signal SendEffectiveHandler Makes an instance of the EffectiveHandler class and handles signal)** **Process – (Takes EmoState and extracts all necessary information** **Send – (Makes instance of the Sender class and begins process of sending final signal)** **Process –(Makes EmoState and extracts all necessary information)** **Send- (Makes instance of the Sender class and begins**	Emotiv Software	Dependent upon particular method	

process of sending signal to car) **ExportSignal- (Sends extracted information)** **ExportPreviousSignal – (Re-sends the previousinformation)**			
Serial.Begin–sets the data rate for communication between board and microcontroller) **Serial.Println –(Prints data to serial ports)** **Serial.Print –(prints data to serial ports)** **Serial.Read – (Read serial data)** **Serial.Avialable- (Get the number of bytes available for readind from serial port)** **Setup –(called when sketch starts , initializes and starts functions)** **Loop – (performs a set of**	Arduino Software	Binary signals and dependent upon particular function	Lee

instructions iteratively) **Compare –(this procedure compares each bit to ASCII equivalent or to specific values)** **Assign- (gives a unique value for each string read)**			

Table 11.2 Emotive commands and corresponding suites and functions.

12. Administration

12.1 Project Budget Estimate

The goal was to build a mind controlled car that would be modestly priced and affordable to four broke college seniors. Never factored in, were plans for any possible consumer interest or make it marketable, so when the initial cap of $1000-$1100 that had been set was smashed by the harsh reality of “things ain’t so cheap” it didn’t hinder any of the proposed ideas, just social lives. The following chart shows some of the materials and the estimates for how much the project will cost, but it will be expected to change even more than it already has as the second semester progresses. We have been pursuing Intel to donate the DH61AG motherboard with the Intel i3 processor to our project due to our groups financial instability but have yet to hear back from them. If we do get the board sponsored by Intel the project budget would decrease dramatically ($250 - $300) which would allow us to expand more into the different kinds of sensors and other add on we could incorporate into the actual car.

Parts	Price Per Part	Quantity	Total Price
Emotiv EPOC headset	$750.00	1	$750.00
PCB board	$100.00	1	$100.00
Motherboard	$250.00-$325.00	1	$250.00-$325.00
Flash disk module	$35.00	1	$35.00
Remote Control Car	$45.00	1	$45.00
DC Drive Motor	$15.00	1	$15.00
DC Servo Motor	$15.00	1	$15.00
Voltage Regulators	$3.00	3	$9.00
Miscellaneous parts	$50.00		$50.00
Ultrasonic Sensor	$10.00	1	$10.00
Total:			**$1279.00-$1354.00**

(Table 12.1) Budget estimate for senior design 1.

12.2 Timeline/Milestones

12.2.1 September

This moth the major goal was the final decision for our design idea. We all brainstormed to come up with the final idea so that it would meet all of the desired bullet points for the electrical engineering criteria. Once the idea was settled upon we split the research up amongst the group according to either computer engineering or electrical engineering. The research would include what kind of EEG headset would be best suited for our needs, what kind of board would meet all of our requirements and be most cost efficient, and if we were going to design and build out own car or buy one and adapt it to our needs. We also have started looking for potential sponsors.

12.2.2 October

For October we still haven't found any potential sponsors, so we have started fundraising from friends and family to ease some of the financial stress. The Emotiv EPOC headset was ordered and delivered so testing could begin on that to ensure knowledge of proper use by the time the second semester comes around. We also figured out that the original platform we wanted to run the Emotiv software on was not powerful enough and have started searching for a better replacement that can support the 2.4 GHz needed. this also reduced the work load on the computer engineers eliminating the need to learn python to write the architecture.

12.2.3 November

In November we finalized most of the designs for the project, with the exception of the motherboard we will be using. We have figured out all of the specs including the proper processor needed but still cannot decide between the Intel DH77DF or the DH61AG mini-ITX motherboards. Training with the headset has taught us that this project will not be as simple to pick up and play with for anyone. We've discovered that a minimum of 5 hours training is required to become fluid enough in thought manipulation to accomplish the tasks that are required to move the car with ease. We settled on the car that will be used in the final project along with the kind of motors, servos, and transmitter/receiver pair.

12.2.4 December

December was a crucial month finalizing everything for our project. All of the background research was completed and almost all of the components had been picked out. We decided on the DH61AG main board as the back bone for our project using the Intel i3 sandy bridge processor. Training on the headset finished and now all motions of the 3D cube can be controlled at will. The budget was also finalized giving us a goal for our fundraising.

12.3 Areas of Assigned Responsibility

The figure below is a block diagram of the roles that were assigned based on major before actually researching into the design of the project in general.

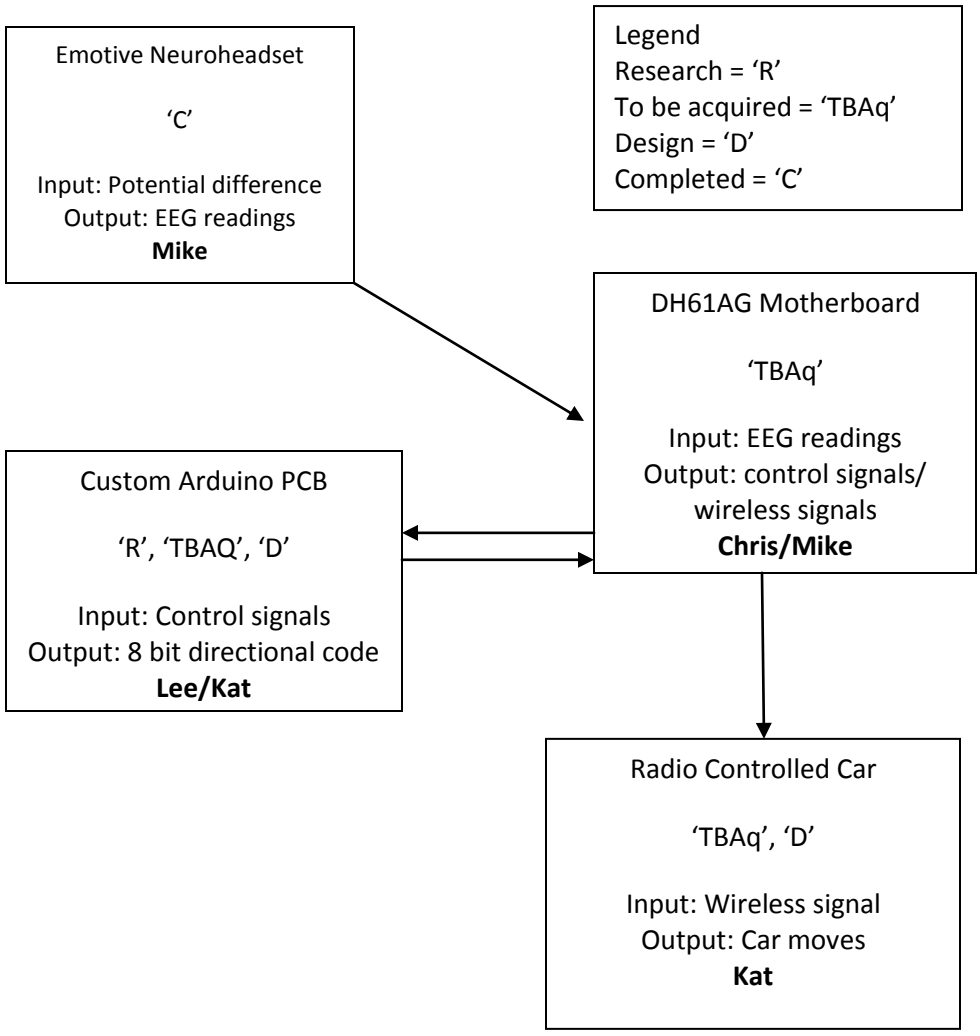


Figure 12.1 Areas of Assigned Responsibility

The people responsible for each portion of the project had to obtain materials and conduct research independently.

- The headset block which included; initial testing, training, and connectivity
- The Motherboard block includes; initial set up, hardware installation, wireless communication and custom architecture for translation program.
- The Arduino PCB will incorporate designing, and programming the transmitting sequencing for wirelessly communicating with the car.
- The Car will comprise; design of a custom PCB, motor and servo install, sensor install, and battery.

Once these roles changed, it helped to better understand which direction the project was going to head in. some research still to be conducted includes exact parts for the onboard PCB for the car, wireless transmitters/receivers, and coding for the Arduino board.

With regards to the paper, parts were assigned accordingly to the area of interest that was initially assigned to each individual. Our responsibilities with the paper included;

- Keeping within the laws of ethics.
- Researching and citing sources accurately and in a orderly fashion.
- Keeping our budget within the set estimate of funding.
- Meeting in an orderly fashion as well as keeping track of what occurs during each meeting.
- Getting the paper done by the deadline set by the professor of the class.

These rules will be adhered to so that we may be able to show good effort towards the final evaluation of our project and of our peers during the next semester within Senior Design II. Once these guidelines are followed we will be able to demonstrate a mastery of skill as well as finalize our development throughout our college career.

13. Summary/Conclusion

It was the general goal of the group to learn about the detection, function, and implementation of EEG readings in a practical instead of medical way. The EPOC-alypse car allowed us to gain experience with dealing with raw EEG data and transforming that data into a code that could be recognized and be used with a remote control car. Researching and designing the actual device has proven to be a very exciting process.

Because there were many more aspects to this project than originally anticipated, designing such a system to incorporate everything that was called for, meant that each member of the project became specialized in a specific area of expertise, be it the headset, motherboard, or car. All the members of the group though have learned the essentials of the components and understand what is necessary to make the car run properly.

It can be noted that the learning curve in general for this project was quite steep, with none of the group members having no background in most of the subjects that this project required. Leaning about the inner workings of the brain is something most electrical and computer engineers don't have to worry about, but for proper operation of the headset it was important to know what area of the brain a sensor pair is situated over and what that specific area of the brain is responsible for.

While difficult for our budget, not having a sponsor proved to be quite beneficial for the creativity of the team. Being able to come up with loop holes around certain problems that were holding up progress without having any outside constraint from a client was to put it simply; nice. The group could be as extravagant or minimal with a certain aspect of the project as they saw fit. As an example take the motherboard. Our original platform to run our software on was a raspberry pie, due to its size and multiple functionalities it seemed like a good choice.

Come to find out later that it was highly improbable that we would be able to develop a custom architecture to interpret EEG signals and would need an extravagant 2.4 GHz to run the Emotiv software on a much larger board. If there had been a sponsor and they had put restrictions on parts or board specs it could be said that that would have made life exceedingly more difficult for the group.

Learning about the different areas of the brain was also a fascinating experience, seeing a predicted response from a certain stimuli and then being able to tell which area of the brain it came from is definitely a skill not many people can say they have. This knowledge came into play the most while testing the headset and training for the 3D cube to perform a second action other than push. This initial roadblock was caused by the brains natural inability to switch from one area of activity to another without the influence of external stimuli. So when a tack was introduced into a shoe and worn to try and train, it was predicted that a response in the somatosensory association cortex would present itself, which it did. This reaction to pain was initially what caused the cube to rotate right. But after a couple weeks of training simply having the shoe with the tack *next* to the foot it was typically on, and concentrating on the pain that it would yield, produced a readout identical to a readout if the tack shoe was being worn. The brains ability to learn this association over such a short time was incredible, and to be able to see the physical patters produced made it that much better.

The brain computer interface aspect of this project limits users to those who have proficient control over isolating thoughts by training with the headset for a period of time. So it does not accommodate our original goal of anyone just being able to put on the Emotiv EPOC headset and being able to drive the car.

The EPOC-alypse car is a design that has a very specific niche. The market for BCI technologies hasn't yet emerged as a mainstream thing. It is reserved for those who want to explore and learn about the emerging field. So there is no target audience or market that this project is directed towards, the ultimate goal of this project is to educate ourselves and others about the used for brain computer interface and possibly pass on our knowledge to those who one day might be able to bring BCI into everyday life.

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16. References

- Bishop, Bryon. "Emotiv EPOC EEG Headset Hacked." *Emotiv EPOC EEG Headset Hacked*. H plus Magazine, 13 Sept. 2010. Web. 27 Nov. 2012. <http://hplusmagazine.com/2010/09/13/emotiv-epoc-eeg-headset-hacked/>.

- "Emotiv Epoc." *LabVIEW Hacker*. N.p., n.d. Web. 27 Nov. 2012. <http://labviewhacker.com/epoc.php>.

- Fairclough, Steve. "Physiological Computing." *: Emotiv EPOC and the Triple Dilemma of Early Adoption*. Physiological Computing, 13 Dec. 2010. Web. 27 Nov. 2012. <http://www.physiologicalcomputing.net/?p=1191>.
- Herman, Stephen L. *Industrial Motor Control: Workbook and Lab Manual, 6E*. 6th ed. Clifton Park, NY: Delmar Cengage Learning, 2010. Print.

- "Proximity Sensor." *Www.sensors-transducers.machinedesign.com*. Machine Design, n.d. Web. 12 Nov. 2012. <http://www.sensors-transducers.machinedesign.com/guiEdits/Content/bdeee4/bdeee4_7.aspx

- Torres, Gabriel. "Everything You Need to Know About The Motherboard." *Hardware Secrets*. N.p., 10 Feb. 2010. Web. 14 Nov. 2012. <http://www.hardwaresecrets.com/article/Everything-You-Need-to-Know-About-The-Motherboard-Voltage-Regulator-Circuit/616/1>.

- "What Is the Difference between a DC Motor and Servo Motor?" *The Handy Board*. N.p., n.d. Web. 14 Nov. 2012. <http://handyboard.com/hb/faq/hardware-faqs/dc-vs-servo/>.

- "Choosing and Using Nickel-Metal-Hydride (NiMH) Rechargeable Batteries." *Http://www.stefanv.com*. N.p., n.d. Web. 16 Nov. 2012. <http://www.stefanv.com/electronics/using_nimh.html>.

- "What's the Best Battery?" *Www.BatteryUniversity.com*. N.p., n.d. Web. 16 Nov. 2012. <http://batteryuniversity.com/learn/article/whats_the_best_battery>.

- "Sensors: Proximity." *Www.EngineersHandbook.com*. N.p., n.d. Web. 17 Nov. 2012. <http://www.engineershandbook.com/Components/proximitysensors.htm>

- Whitlock, Bill. "UNDERSTANDING and Controlling RF Interference." *Sound & Video Contractor*. N.p., 1 Feb. 1999. Web. 18 Nov. 2012. <http://svconline.com/mag/avinstall_understanding_controlling_rf/>.
- Brain, Marshall, Charles W. Bryant and Clint Pumphrey. "How Batteries Work" 01 April 2000. HowStuffWorks.com. <http://electronics.howstuffworks.com/everyday-tech/battery.htm> 18 Nov. 2012.

- Berman, Eric, Kalyn Kovac, and Bruno Umeadi. *Mind-controlled R/C Car*. Tech. N.p., n.d. Web. <http://cratel.wichita.edu/blogs/eecsfinalreportspr2012mindcontrolledrccar/>.

- Bothra, Jitendra, and Baturalp Torun. "SWARM Extreme." *SWARM Extreme*. N.p., n.d. Web. <http://www.slideshare.net/bet3/swarm-extreme>.

- Emotiv. Emotiv Software Development Kit User Manual for Release 1.0.0.5.

- Rouse, Margaret. "Event-Driven Architecture (EDA)." *SearchSOA*. N.p., n.d. Web. <http://searchsoa.techtarget.com/definition/event-driven-architecture>.

- Vourvopoulos, A., Brain-controlled NXT Robot - Tele-operating a robot through brain electrical activity, Bachelor's Thesis, Department of Engineering and Computing, Coventry University, UK, (2011).

- Bruce CJ, Goldberg ME, Bushnell MC, Stanton GB. (1985). "Primate frontal eye fields. II. Physiological and anatomical correlates of electrically evoked eye movements.". *Journal of Neurophysiology* **54** (3): 714–734. PMID 4045546.

- Kirchner H, Barbeau EJ, Thorpe SJ, Régis J, Liégeois-Chauvel C. (2009). "Ultra-Rapid Sensory Responses in the Human Frontal Eye Field Region".*Journal of Neuroscience* **29** (23): 7599–7606.doi:10.1523/JNEUROSCI.1233-09.2009.

.

- Philip David Zelazo and Ulrich Muller: *Executive function in typical and atypical development*, in: Usha Goswam (ed): Blackwell Handbook of Child Cognitive Development, 2002

- Philip David Zelazo and Ulrich Muller: *Executive function in typical and atypical development*, in: Usha Goswam (ed): Blackwell Handbook of Child Cognitive Development, 2002

- Brodmann K. Vergleichende Lokalisationslehre der Grosshirnrinde. Leipzig : Johann Ambrosius Bart, 1909

- Brent A. Vogt, Deepak N. Pandya, Douglas L. Rosene (August 1987). "Cingulate cortex of the rhesus monkey: I. Cytoarchitecture and thalamic afferents". *The Journal of Comparative Neurology* **262** (2): 256–270.

- Burgess, P.W., Dumontheil, I., & Gilbert, S.J. (2007). The gateway hypothesis of rostral prefrontal cortex (area 10) function. Trends in Cognitive Science, Vol. 11, No. 7

- Ramnani N, Owen AM. (2004). Anterior prefrontal cortex: insights into function from anatomy and neuroimaging. Nat Rev Neurosci. 5(3):184-94.

- Semendeferi K, Armstrong E, Schleicher A, Zilles K, Van Hoesen GW. (2001). Prefrontal cortex in humans and apes: a comparative study of area 10. Am J Phys Anthropol.

- Rivara CB, Sherwood CC, Bouras C, and Hof PR (2003). "Stereologic characterization and spatial distribution patterns of Betz cells in the human primary motor cortex". *The anatomical record. Part A, Discoveries in molecular, cellular, and evolutionary biology* **270**: 137-151

- Lassek, A.M. (1941). "The pyramidal tract of the monkey". *J. Comp. Neurol* **74**: 193-202.

- “Human brain.” www.en.wikipedia.org. Web. 12 Oct 2012 < http://en.wikipedia.org/wiki/Human_brain >.

- Busey, Tom. “Brain Structure.” www.cognitrn.psych.indiana.edu. University of Indiana, Web. 1 Nov 2012 <http://cognitrn.psych.indiana.edu/busey/Q301/BrainStructure.html>.

- “Arduino.” www.en.wikipedia.org. Web. 29 Nov 2012 < http://en.wikipedia.org/wiki/Arduino >.

- “Printed circuit board.” www.en.wikipedia.org. Web 20 Sept 2012 <http://en.wikipedia.org/wiki/Printed_circuit_board >.

- “Arduino Tutorial.” www.ladyada.net. 27 April 2012. Web. 1 Dec 2012 <http://www.ladyada.net/learn/arduino/index.html >.

- “ATmega328.” www.atmel.com. Web. 1 Dec 2012 <http://www.atmel.com/devices/atmega328.aspx?tab=overview>.

- “ARDUINO.” arduino.cc/en/. Web. 1 Dec 2012 <http://arduino.cc/en/ >.

- Ogawa S**,** Tank DW, Menon R, Ellermann JM, Kim SG, Merkle H, and Ugurbil K. Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. *Proc Natl Acad Sci USA 89*: *5951*–5955, *1992*.

- Pierce, Kate. "The Brain Responds To Music The Same Way As Eating." *The Huffington Post*. TheHuffingtonPost.com, 10 Jan. 2011. Web. 05 Dec. 2012.

- Purves, D., Augustine, G. J., Fitzpatrick, D., Hall, W., LaMantia, A., McNamara, J. O., & White, L. E. (Eds.). (2008). Neuroscience (4th ed.). Sunderland, MA: Sinauer Associates.

17. Permission of use

[Christopher] Hello, I would like to know who I would need to talk to in order to get written permission to use and cite the User's Manual included in the LITE SDK. I was directed to the media page earlier, but that does not have anything for the User's Manual. The purpose of this is strictly for research documentation and WILL NOT be used for any other purpose. Please let me know.
[Kimberly] Hello, welcome to Emotiv! My name is Kimberly. How may I help you today?
[Kimberly] I answered your support ticket.
[Christopher] Oh, perfect. You are who I wanted to speak to
[Kimberly] The information that I gave you is the only information that is available to be used.
[Christopher] Ok, so there is no way of attaining permission to use the manual? We just want to be able to use some of the figures included, such as the enums and data structrues in order to explain how the sdk is used
[Christopher] it is for a research document for my university
[Christopher] the user's manual is included in the download that is open to the public, but we are not sure if we need permissions to use it
[Kimberly] I will be glad to ask, however, we have not allowed it in the past except for those images, etc. that I mentioned in the support ticket.
[Christopher] Ok, please let me know. This is crucial for our research and we would like to make it as thorough as possible
[Christopher] Maybe there is someone else I can talk to in regards to this?
[Kimberly] Do you have SDKLite?
[Kimberly] Or one of the other SDKs?
[Christopher] Yes, we have SDKLite as well as the research SDK
[Kimberly] Then you can use if for the purposes that you stated as long as it is correctly mentioned.
[Christopher] Thank you very much. I very much appreciate your help!
[Christopher] We will be sure to include all necessary citations and references
[Kimberly] Thank you for contacting Emotiv.